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DEEPWATER PORTS APPROACH/EXIT HAZARD AND RISK ASSESSMENT.(U)

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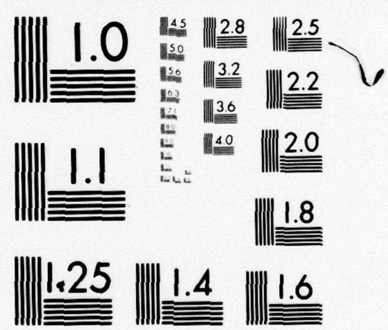

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DEEPWATER PORTS APPROACH/EXIT HAZARD AND RISK ASSESSMENT

Planning Research Corporation
Systems Services Company
7600 Old Springhouse Road
McLean, VA 22102

FEBRUARY 1979
FINAL REPORT

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The Contracting Officer's Technical Representative for the project was Dr. John S. Gardenier, with Dr. Ping C. Chuang as backup. The Deepwater Port Project monitors were CDR J. E. MARGESON, LCDR R. J. IMBRIE, and LT P. T. NEISWANDER.

16. Abstract

Two deepwater ports are planned for crude oil importation in the Gulf of Mexico: the Louisiana Offshore Oil Port (LOOP) and the Texas Offshore Oil Terminal, which replaces the planned SEADOCK terminal. This report presents the results of an evaluation of the potential hazards to navigation and an assessment of the risk of oil spills from deepwater port tanker transits in the Gulf. The route from the Straits of Florida and Yucatan Channel to the ports was divided into five transit zones, and the primary hazards were identified and ranked by transit zone. Vessel accident causal data from the Coast Guard's Vessel Casualty Reporting System were used for the ranking in conjunction with a subjective analysis based on personal observations of deepwater port operations and tanker operations in the Gulf of Mexico, analysis of Gulf weather data and vessel traffic, and "paper transits" of the deepwater port tanker routes.

The oil spill risk assessment estimated the expected number of oil spills, the probability distribution of amount spilled, and the probability of at least one spill exceeding a given amount. These risk measures were evaluated by transit zone and casualty type (impact and nonimpact) over a 30 year operating period for the two ports. The oil spill data utilized were obtained from the Coast Guard's Tanker Casualty Data.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

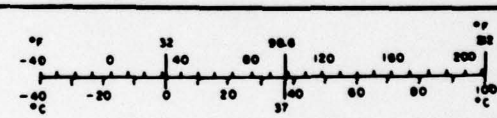

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TABLE OF CONTENTS

(4)

LIST OF FIGURES

5

(10) (8)

9

		Page
Figure D-9	Visual/Radar Lookout LTA	266
Figure D-10	Assessment of Speed Over the Ground LTA	270
Figure D-11	Assessment of Approach Angle/Distance LTA	274
Figure D-12	Depth Surveillance LTA	277
Figure D-13	Assessment of Hazards/Shoals LTA	280
Figure D-14	Precautions for Traffic LTA	281
Figure D-15	Closing Maneuver LTA	284
Figure D-16	Crossing and Overtaking Maneuver LTA	285
Figure D-17	Assessment of Angle/Distance to Other Vessel LTA	286
Figure D-18	DWP Close Proximity Operations LTA	289

APPENDIX F

~~IX~~ 10

Page

LIST OF TABLES

13

		Page
Table V-4	Average Spill Sizes By Cumulative Vessel Size Group	99
Table V-5	Oil Spill Data From Tanker Casualty File	101
Table V-6	Surrogate Transit Zones	104
Table V-7	Goodness of Fit Results for Spill Frequency	106
Table V-8	Spill Rate Values	107
Table V-9	Expected Number of Spills for LOOP by Transit Zone, Casualty Type, and Time Period	108
Table V-10	Expected Number of Spills for SEADOCK by Transit Zone, Casualty Type, and Time Period	109
Table V-11	Spill Size Date	111
Table V-12	Spill Size Curve Fit Data for Log Normal, Gamma, and Inverted Gamma Distributions	116
Table V-13	Tanker Casualty Spill Size Statistics by Type of Casualty	118
Table V-14	Expected Amount Spilled for LOOP by Transit Zone, Casualty Type and Time Period	126
Table V-15	Expected Amount Spilled for SEADOCK by Transit Zone, Casualty Type and Time Period	127
Table V-16	Major Tanker Casualty Oil Spills in the World (1967-1978)	130
Table V-17	Probability of Large Spill Sizes During Deepwater Port Operations (30-Year Period)	131
Table V-18	Probability of at Least One Spill Greater Than That of the Amoco Cadiz by Time Period and Zone for LOOP	133
Table V-19	Probability of at Least One Spill Greater Than That of the Torrey Canyon by Time Period and Zone for LOOP	134
Table V-20	Probability of at Least One Spill Greater Than That of the Amoco Cadiz by Time Period and Zone for SEADOCK	135
Table V-21	Probability of at Least One Spill Greater Than That of the Torrey Canyon By Time Period and Zone for SEADOCK	136

COMMENTS

Background

This study began with an assumption that a more concise and specific set of hazards of deepwater port navigation would be identified than was actually found. It was anticipated that various advanced technological systems would be identified as the major safety improvements. Systems cost-benefit analyses were then to be conducted to determine the "best available technology".

The study results reflect a less structured view of the real world, as opposed to the neat technical framework of analysts and engineers. There may indeed be substantial benefits of new, high technology systems. The needs that appear obvious from the study, however, are more procedural and commonplace. They can be met without continued research into futuristic systems.

Purpose

Because the contractor was not required to prepare a list of new safety measures, there is no such list in the report. The Coast Guard project personnel responsible for the study, however, feel that the report would be incomplete in a practical (although not a contractual) sense without a discussion of possible ways to improve Deepwater Port navigation safety. The following paragraphs extend the discussion to be found in the Conclusions and Recommendations section of the report, especially pages 23 through 28. The reader should come back to this material after reading the Executive Summary and Introduction of the main report.

Two types of hazard dominate deepwater port navigational accident risk in the Gulf of Mexico: (1) human factors and (2) heavy weather. Various other identified hazards can be looked upon as adding to the dangers of those two basic hazard types. Two additional types of hazards are independently significant: (3) offshore oil rigs or other fixed structures and (4) floating debris. Each of these four categories will be discussed in turn.

Human Factors

The term human factors is used here in referring to any problem of perception, recognition, decision, action or inaction by persons who affect a vessel's movements, which might contribute to a navigation accident. In the language of the maritime accident investigator, the alternative term "personnel fault" implies that no mechanical failure or overwhelming environmental force could be blamed for an accident, although mechanical or environmental factors might contribute to the difficulties faced by the human beings.

Generally, a navigational accident may be thought of as the result of a deviation - from a safe course or from a lawful and appropriate collision avoidance path. A deviation may be gradual and cumulative, as when an undetected current gradually carries a vessel off course; or it may be a sudden deviation based on a mistake. These deviations need not lead to accidents. Given enough depth of water, maneuvering room, and time to detect and/or correct a problem, accidents are generally avoided. The report points out that presence of traffic or obstructions, lack of ample water depth, or conditions which inhibit the detection and correction of navigational problems increase the risk of accident. The risk of accident may also be increased by vessels (such as some fishing or recreational vessels) whose operators lack fully professional standards of training and skill in navigation, communication, and/or shiphandling.

For these reasons, the deepwater port navigation hazards relating to human factors are worst in those areas of relatively restricted waters. These are, primarily, the immediate vicinities of the ports and, secondarily, the Florida Straits and the channels between the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. Within the port safety zones and traffic separation schemes, the hazards are partly offset by: (1) requiring mooring masters with detailed local knowledge and a high degree of professional skill on a variety of tankers; (2) providing a vessel traffic service with radar and radio to assist masters hindered by low visibility or lack of information regarding other traffic or special conditions in and around the port area; and (3) limiting or prohibiting the movement of vessels under very hazardous weather conditions.

Additional safety measures that might be considered could include specialized operational training of mooring masters to handle: unusual vessels, usual vessels under unusual loading conditions, unusual currents, failures of vessel steering or propulsion systems, difficulties of coordination which might arise on a ship's bridge due to language or other human factors problems, procedures for coping with non-deepwater-port vessels should they enter the port area during tanker operations, or any other reasonably foreseeable, but abnormal, operating conditions.

Apart from measures aimed at port personnel, it would be useful to assist ships' masters in the port vicinity in case of trouble before the mooring master comes on board. One example would be possible disorientation of a master approaching the mooring master boarding area in unexpectedly low visibility. It could be especially dangerous if it also happened that there would be a delay in getting the mooring master on board. The single point moorings and the anchorage are inboard of the boarding area (see diagrams, pp. 14 and 16). The presence of fixed structures close by the safety fairway and the traffic separation scheme lanes requires assured position keeping, which can be difficult for unassisted large tankers.

If storm conditions arise unexpectedly while a large tanker is moored or anchored within the port area, it might be difficult or even impossible to put a mooring master on board for purposes of taking that tanker out to sea. Moreover, the vessel might be in an unusual load condition for getting underway and might experience unusual currents. Port advisory procedures to assist the tanker master in such circumstances might be worked out ahead of time.

Apart from the specific situations mentioned above, it would be useful for the deepwater port operators/involved tanker operating community to attempt to define other realistic scenarios that are unusual and dangerous. Special operating procedures could be planned before emergency conditions arose. It is obviously impractical to attempt to require perfect foresight or problem-solving; it is even difficult to define or enforce a requirement that a "reasonable" effort be made. It might be useful for the Coast Guard to encourage and participate in discussions for this purpose from time to time in whatever settings seem appropriate to the parties involved. Those results mutually agreed to could become revisions or additions to the port operations manual.

Standard port operating procedures, as opposed to special emergency procedures, are being laid out. Even these could create hazards. For example, it is generally safer to have only one tanker maneuvering within the safety zone or within the traffic separation scheme, although situations can probably be identified where even that is not the case. It should never be assumed that standard operating procedures are so perfectly foresighted that they could not be inappropriate to the situation at hand. Procedures should neither be followed blindly not casually ignored.

Heavy Weather

Weather guidelines are currently required for suspending port operations. It is apparent from the report that guidelines are also required for procedures which will allow the tankers to get underway safely. Considering the slow initial speeds of large tankers and the presumably deteriorating conditions of wind and sea state which would prompt the evacuations, port evacuation could be difficult to accomplish. Mooring masters might not be able to board the vessels. Masters may be reluctant to accept risks of waiting for a mooring master if they judge that their vessel is endangered. There can be no perfect answer to these problems, which pertain to shoreside ports as well. To the extent that emergency procedures and guidelines can be developed, they should be included in the port operations manuals.

Outside the safety zone and traffic separation scheme, heavy weather hazards, like human factors hazards, are reduced by the availability of ample maneuvering room and water depth. The report points out that the dangers from hurricanes are well understood. Basic procedures for recognizing when storms are threatening and for minimizing the hazards to a ship that is caught in a hurricane have been part of the sailor's fundamental training for many years. Vessels are designed with the understanding by naval architects that they will have to be sufficiently strong to withstand an occasional severe storm.

More recently, additional precautions have been added to provide still further reduction of the risks due to storms. U. S. vessels have typically been subjected to periodic hull inspections, aimed at detecting and repairing incipient hull cracking, weld faults, or deterioration of the plates. Some, but not all, foreign nations also have rigorous inspection programs.

The Port and Tanker Safety Act of 1978 authorizes and directs inspection of foreign vessels and the barring from U. S. port entry of vessels with a history of inadequacies of equipment or seaworthiness. The Deepwater Port Act of 1974 defines the ports referred to in this study as U. S. ports even though they are outside the three mile limit of our territorial sea. It further requires all foreign and U. S. vessels using the port to agree to subject themselves to U. S. law while in the port.

Weather satellites and sophisticated computer analysis and forecasting methods are now used to detect any tropical storms forming in the Gulf, to track their paths, to monitor their intensity, and to forecast their movements. These methods are in addition to pre-satellite methods of detecting and tracking storms. Weather advisories are routinely broadcast to vessels at sea. The locations, frequencies, and schedules of weather broadcasting stations are routinely available to all mariners. In addition, the Deepwater Port operators are planning to include this information in the operating manuals they provide to calling vessels.

It is not necessarily true that every precaution will be used. Not all of the watch officers who will be directing vessels in the vicinity of the Gulf are seasoned, experienced masters; some will be relatively junior, inexperienced officers. It is also not true that weather advisories will necessarily be received and understood by the vessels. The radio may be off, out of order, or not tuned to a weather channel. There may be no personnel on watch on the bridge with a sufficient command of the English language to understand a weather warning. Even given that a warning is received and understood, it may not be acted upon appropriately.

It is impossible to assure that none of these problems will occur or, if they occur, that they would not lead to an accident and a possible oil spill. Several measures might be considered, however, that could lessen the remaining risk. One possibility would be to encourage tanker operators to have on watch at all times while in the Straits or the Gulf a person fluent in at least one language in which weather advisories are broadcast. Another possibility would be to consider broadcasting weather advisories in additional languages.

It might be feasible to encourage or require vessels calling at the ports to have on board standing procedures for watch officers to assure response to weather warnings in accordance with accepted practices of good seamanship. It is not clear, however, that such procedures could be legally required. If they were required but were resented, that they would probably not be enforced effectively by the tanker owners/masters. Some form of education/advisory/warning enhancement effort may be desirable. Determining the right form and extent is beyond the scope of this study.

Even when a sound ship is well captained and suitably warned, it is possible for tropical storms to endanger a vessel. In recent years, there has been research aimed at developing operational hull stress monitoring, analysis, and readout systems to provide precise, computer-assisted data for a master to use in steering his vessel so as to minimize wave-induced hull strain. The technical/economical availability of such systems does not appear imminent, however. It is also true that there are available commercial "weather routing" services, but these are oriented to fuel economy during long voyages, not to precise storm avoidance in any specific route segment.

Offshore Oil Rigs or Other Fixed Structures

The report notes that the risk of ramming offshore rigs is significant in the Gulf. The risk is potentially severe along those portions of Gulf safety fairways where drilling operations are now conducted or will be during the operating life of the deepwater ports. It is also potentially severe in case vessels do not follow the fairways either as a matter of choice or inadvertantly.

The deepwater port operators will provide warnings of rig operations out to ten miles on either side of the specific approach fairways to their respective ports. They will not provide a similar service with respect to other Gulf fairways because they do not have the responsibility or any monitoring capability at the ranges involved.

The safety fairways are mandatory only in the sense that no fixed structure can be legally placed within their boundaries. They are not mandatory navigation routes. They are not the most economical routes, aside from considerations of safety. They are not universally accepted by experienced mariners as the only conceivable prudent routes, even when safety is a paramount consideration.

Assuming that a master chooses to follow a safety fairway, his ability to stay within the limits of the two-mile-wide fairways is normally good. It can be degraded by errors in navigation instruments or in the reading of them, by failures of propulsion or steering systems, by inefficient or inattentive performance of duties by watchstanders, by low visibility, or by high winds or heavy seas.

Tanker personnel should normally have no difficulty is detecting and avoiding mobile offshore drill rigs. These tend to be large, highly visible structures, well-lighted at night, and offering a strong radar return. In case of bad weather and any sort of problem with the efficient use of a ship's radar, however, it could be easy to fail to detect even a large structure. In contrast to the mobile, exploratory rigs, some of the production rigs are smaller and less visible by eye or radar.

Oil rig locations get plotted on nautical charts, and should thus be known to sailors and should be avoided. There is a time lag, however, from the placement of rigs to their appearance on charts. Mariner advisories are issued, but may not be noted or plotted. There may be a position error in the advisory or on the chart. Individual ships may not obtain the latest charts. Individual watchstanders may not consult the charts, may misread them, or may err with regard to their own position or track.

As with hurricanes, the dangers of offshore rigs are recognized and procedures are in use to limit those dangers. It is not obvious what additional steps are appropriate specifically for deepwater port operations, other than inclusion of a discussion in the port manual. The Port and Tanker Safety Act of 1978 provides for assuring that crews of foreign vessels calling at U. S. ports have similar qualifications to U. S. licensed mariners; consideration of possible monitoring/enforcement methods for implementing that precaution is underway now. As standards of training and qualification of U. S. crews are raised, it would be desirable to include training in the various factors that contribute to the dangers to ships posed by offshore fixed structures. Hopefully, those standards could also then be effectively applied to crews of foreign tankers calling at the deepwater ports - and at U. S. shoreside ports as well.

Any practical measures that would enhance the accurate and timely reporting, advising, and charting of rig positions would be helpful. The feasibility of an effort to require or encourage, and to monitor, the adequacy of lighting, day visibility, and radar reflectance of offshore fixed structures should be investigated.

The final possibility is to find some means of enhancing the distribution of up-to-date charts, such as by stocking at the deepwater ports, and/or inspections to assure that up-to-date charts are on board the calling tankers.

Floating or Submerged Debris

The report points to six recorded instances of offshore debris rammings in the Gulf of Mexico from 1969 through 1977. Large tankers, due to their hull strength and the depth of their screws, may be less susceptible than are smaller vessels. This hazard is controversial; some masters are concerned about debris, others are not. Precautionary measures and further appraisal are recommended.

It is known that the Mississippi and other rivers do carry large amounts of debris into the Gulf each spring. Drift patterns, composition, depth at which debris floats, how long it remains adrift in the Gulf are all uncertainties which concern safety analysts. It is not known whether the problem, if indeed it is significant at all to deepwater port operations, is seasonal, or dependent on Gulf storms, or dependent on heavy rainfalls inland.

Possibilities for action should address both warnings and efforts to improve the understanding and evaluation of the hazard. Warnings could include a brief mention in the port operations manuals. If the hazard is judged severe (in general or at particular times), it might be wise to include reminders of the hazard in the 72 hour and 48 hour advance contacts by high frequency, single sideband radio. A voluntary or mandatory system might be established whereby vessels record debris sightings/incidents by time, position, and weather conditions. Such data could be collected by the deepwater ports for their own use and/or relayed to the Coast Guard. A temporary or permanent data bank and analysis function could be established to improve information on the extent, patterns, timing, and nature of the debris hazard. All vessels in the Gulf Coast area could be encouraged to contribute to such a system.

General

None of the recommendations above are intended to replace tanker navigation safety measures that are otherwise planned, required, or implicit in prudent seamanship or port management. Some of the recommendations made here may be already planned; others may be impractical operationally. They are intended only to assist responsible industry and government officials in applying the results of this study.

Pages 1 thru 423 follows

I. EXECUTIVE SUMMARY

This report documents an evaluation of the potential hazards to navigation and a prediction of the risks of oil spills associated with the operation of two deepwater ports planned for the Gulf of Mexico. The ports evaluated are the Louisiana Offshore Oil Port (LOOP) to be located 13.5 miles off the Louisiana Coast, and the Texas Offshore Oil Terminal which is to be located 20 miles off the Texas Coast, south of Freeport (see figure I-1).

The Texas port, projected for start-up in 1982, is planned as a replacement for SEADOCK whose application has been withdrawn by the sponsors. Since current indications are that the Texas port is to use SEADOCK plans, the name SEADOCK and the SEADOCK characteristics are used in this study to represent the Texas port. The estimates given herein of ship mix, port calls, and volume throughput were obtained from the SEADOCK planning documents. The original SEADOCK start-up time of 1980 is assumed for purposes of analysis.

Each facility will have a safety zone comprising a pumping platform complex surrounded by a single point mooring. Entrance to (and exit from) the port facility by the tankers will be via a safety fairway beginning at the 1,000 meter depth contour followed by a traffic separation scheme 5 to 6 miles long and 2 miles wide leading to the safety zone.

The purposes of the analysis are (1) to identify the primary hazards to tanker navigation during deepwater port approaches (from entry into the Gulf of Mexico to the deepwater ports), and (2) to quantitatively evaluate the risks of oil spills resulting from tanker casualties over the initial 30 years of operation of the ports. Spills from transfer operations[1] or tank cleaning were not addressed in this study. A companion task within the deepwater port study identifies and summarizes measures (navigational, procedural, and structural) that might mitigate the oil spill risks from tanker casualties. The task report[2] describes technologies and services planned for deepwater port operations and significant available alternatives.

1. This problem is addressed in a separate study: Science Applications, Inc. Deepwater Port Inspection Methods and Procedures, prepared for the U.S. Coast Guard, March 1978.

2. PRC Systems Services Company, Deepwater Ports Approach/Exit-Technology/Service Alternatives, prepared for the U.S. Coast Guard, February 1979.

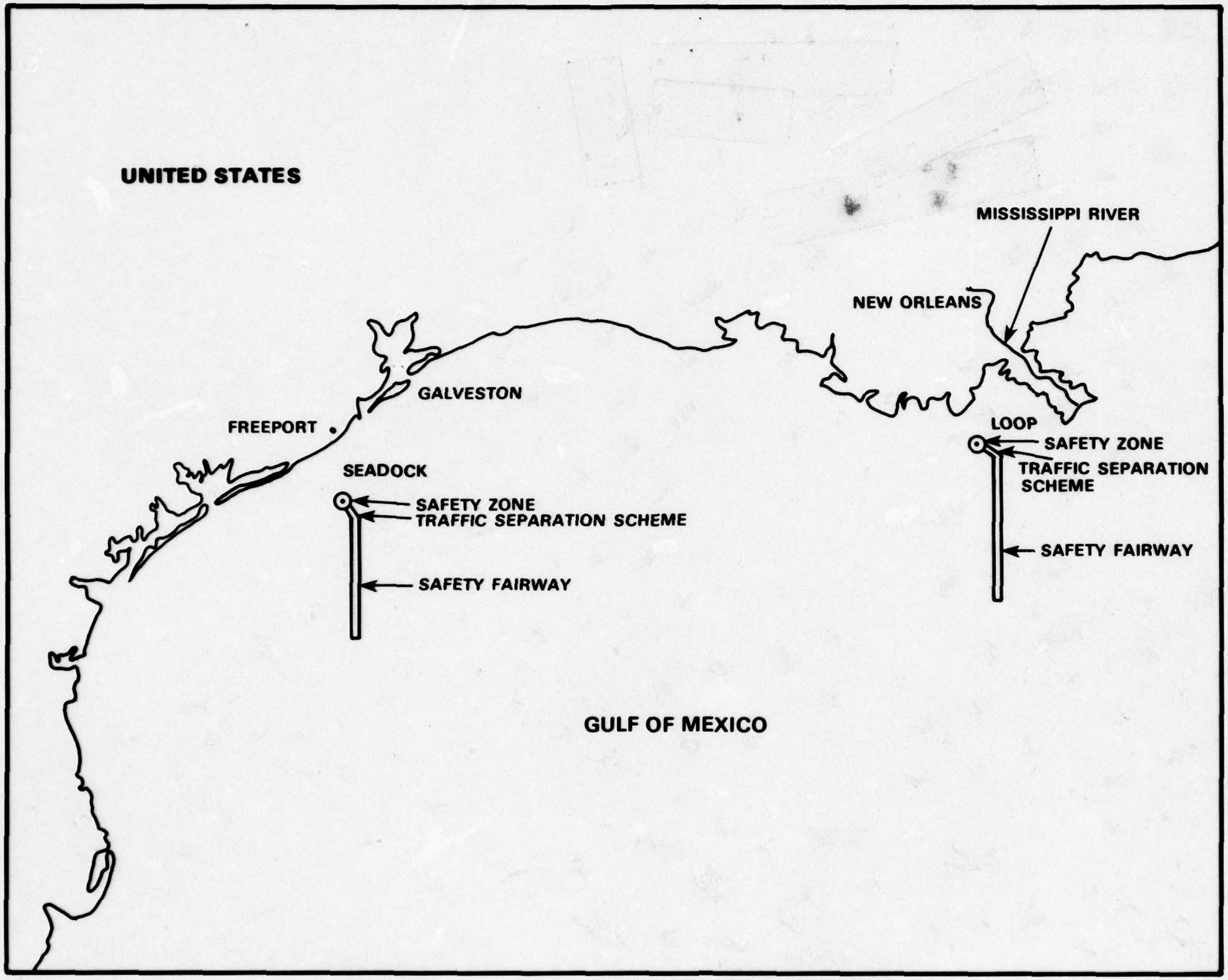

FIGURE I-1. LOOP AND SEADOCK LOCATIONS

The results of the oil spill risk assessment provide a basis for determining whether the risks are expected to be of sufficient magnitude to be of concern. The hazard identification and ranking analysis indicates the primary hazards that should be addressed to reduce risks.

If the risks are judged to be significant and if promising measures to reduce the hazards are evident, the next phase of the study will address the evaluation of selected safety measures. The evaluation will be made in a cost-benefit framework. For each measure, the life-cycle costs will be estimated by marine regulation costing methods and benefits will be estimated from the expected reduction in oil spills. This will allow a comparison of alternative measures and will provide a basis for determining whether any specified measure is expected to result in sufficient benefits relative to its cost.

The oil spill risk analysis involves three measures of risk:

- o Expected number of oil spills.
- o Probability distribution for total amount spilled.
- o Probability of a spill larger than a specified value.

These measures are evaluated by transit zone (straits and channels entering the Gulf of Mexico, the Gulf open sea, the safety fairway, the traffic separation scheme, and the safety zone), by 5-year period, and by casualty type.

The spill probabilities are based upon analysis of historical oil tanker spill data obtained from the Coast Guard's Tanker Casualty File. This automated file contains information on worldwide tanker casualties and resulting oil spills based upon Lloyd's of London reports.

Impact casualty (collision, rammings, and groundings) spill rates are expressed in terms of port calls based upon the results of a statistical analysis that shows a strong linear relationship (correlation coefficient = 0.98) between port calls and impact casulaties. The analysis, performed for seven major U.S. port systems, utilized the Vessel Casualty Reporting System data for tanker accidents and Waterborne Commerce statistics for port calls. Analysis of non-impact casualties (fires, explosions, breakdowns, structural failures, and capsizings) showed no such relationship. Tanker-days at sea and loading/unloading was therefore used as the exposure measure for these casualty types.

Because there are no historical oil spill data available that directly apply to the deepwater port operations, surrogates were used in the analysis. These surrogates were selected on the basis of similarity to deepwater port environments and availability of data. The data base used in the analysis, the Tanker Casualty File, categorizes the site of each casualty by location type: pier, harbor, harbor entrance, coastal, and open sea. These

location types were used as surrogates for the deepwater port transit zones according to the following scheme.

Transit Zones	Data File Location Types
Yucatan Strait, Florida Strait	Coastal
Gulf Open Sea	Open Sea
Safety Fairways, Traffic Separation Schemes	Harbor Entrance
Safety Zones	Harbor Excluding Piers

Since statistical tests showed no significant difference between spill data for the Gulf of Mexico and the world, worldwide tanker casualty data were used. Analysis of spill sizes for various tanker sizes indicate a significant difference between tankers less than and those larger than 20,000 deadweight tons (DWT), with no significant differences among sizes above 20,000 DWT. Therefore, to reflect the types of tankers expected to be involved in deepwater port operations, the data used in the analysis excluded tankers under 20,000 DWT.

The spill frequency distribution utilized in the analysis is the negative binomial, which fits the data slightly better than the Poisson distribution. Several spill size distributions were analyzed; the log-normal was selected based upon considerations of statistical goodness-of-fit tests and the desire to adequately reflect probabilities of very large spills.

The spill rates derived in the study are approximately 5 spills per 10,000 port calls for impact casualty spills and 17 spills per 1,000,000 tanker-days for non-impact casualty spills. Applying these rates to the anticipated traffic volumes for the two deepwater ports results in an expected number of navigation accident spills for LOOP and SEADOCK over a 30-year period of 11 and 17, respectively. SEADOCK values are higher because of the larger projected traffic and longer transit distance within the Gulf. It is estimated that over 85 percent of the spills will result from impact casualties. Over half of the spills are expected to occur in the straits and channels with another 20 percent in the safety zone.

The expected amount of oil spilled for the 30-year period for LOOP is estimated to be 53,700 long tons, of which 38,400 long tons (72 percent) are ascribed to impact casulaties. For SEADOCK, the total expected amount spilled is estimated to be 86,500 long tons, of which 57,300 long tons (66 percent) are ascribed to impact casualties. The approximate percentages of total expected oil spillage by zone for LOOP are: straits and channels - 41%,

Gulf open sea - 21%, safety fairway and traffic separation scheme - 13%, and safety zone - 26%. For SEADOCK, the values are: straits and channels - 38%, Gulf open sea - 27%, safety fairway and traffic separation scheme - 11%, and safety zone - 24%. These percentages differ between the two ports because of the longer transit distance to SEADOCK.

Although 45 percent of the spills are expected to be less than 500 long tons, the likelihood of very large spills is significant. The probability of a spill at least as large as that of the Amoco Cadiz (220,000 long tons) is conservatively estimated at 6 percent, which implies an average time between spills of such size of 490 years. For a spill at least as large as the Torrey Canyon Spill (109,500 long tons), the estimated probability is 25 percent and the average time between such spills is 120 years.

These probability and expected value estimates imply a significant risk of oil spillage from deepwater port tanker casualties. Although it is not within the scope of this study to analyze alternatives to the deepwater ports, it is judged likely that the risks associated with transporting the same amount of oil by other alternatives such as offshore lightering, deepening existing Gulf ports, or transhipment from the Caribbean with smaller tankers, would entail larger risks, due to greater exposure to shallow, restricted waters and greater traffic.

It should be emphasized that these estimates are based upon projections of fleet sizes and volumes to be handled over a period of 30 years. The actual values realized could, of course, differ significantly from these projections. Further, because there is no direct deepwater port data upon which to base the risk evaluations, a number of assumptions regarding tanker operations and casualties in deepwater port transits were necessary. Primary among these assumptions are:

- The casualty-inducing factors (personnel errors, adverse weather, vessel traffic, etc.) for deepwater port tanker transits will not differ significantly from that o current tanker operations in standard ports. However, deepwater ports will represent somewhat smaller risks because of less congestion and very little likelihood of grounding in the approaches.

- Voluntary rules such as use of safety fairways will not necessarily be adhered to by the deepwater port tankers.

- The distribution of spill sizes will tend to remain the same as in the past despite the increase in tanker sizes.

- The data base used (the Tanker Casualty File) reflects the true oil spill frequency.

The first two assumptions are considered conservative or pessimistic. Deepwater port operations could conceiveably be much safer than standard tanker operations if fairways are adhered to and traffic control maintained. The third assumption may be optimistic because, although no evidence was found to indicate a trend in spill sizes with time or with tanker size (for tankers above 20,000 DWT), tankers of the sizes projected for the deepwater ports could result in larger spills than those in the data base, which is for the years 1969-73. The last assumption is also optimistic since some oil spill incidents may have been missed by the data system.

To allow more efficient use of the casualty data for risk analysis, several improvements in the Vessel Casualty Reporting System are recommended:

- o Add spill size information.
- o Add casualty location type (i.e., piers, harbors, entrances, etc.).
- o Reorganize causal data so that they are more useful for casualty cause analysis.

As pointed out in the discussion on fault trees (section VI.A.4), trees such as those present in appendix D could prove useful in reorganizing the causal data portion of the VCRS to provide a more structured basis for causal analyses. This is particularly important for personnel fault casualties, which represent a significant proportion of the tanker casualties.

The hazard identication and ranking analysis was based upon two distinct types of information. First, causal data from the Vessel Casualty Reporting System (VCRS) were analyzed. The system contains up to four causal and contributing factors for each casualty. In addition, the system specifies the type of casualty such as collision with offshore rigs, collision with vessel, overtaking situation, which may also implicitly reflect causal factors. The causal factors were equated with hazards for purposes of this study.

The hazard ranking was performed by transit zone with the same surrogates as in the probability evaluation. Since the VCRS does not specify location type, the casualties from that file were matched with the Tanker Casualty File which contains location information in terms of harbor, harbor entrances, open sea, etc. A total of 97 casualties resulting from correlating these two files were used for the analysis. This allowed identification and quantification of causal factors by transit zone. For each surrogate transit zone, the number of times each hazard was cited as a causal factor or was contained implicity in the casualty definition (e.g., collision with an offshore rig implies the rig as a hazard) was determined from the casulaty data and recorded. In many cases, more than one hazard was cited for a casualty, for example, collision with an offshore rig in the fog may represent two hazards - rigs and low visibility. A hazard criticality index was developed to reflect the relative

contribution of each hazard to vessel operations over the deepwater port transit. This index is the "equivalent" number of casualties caused by each hazard. If two hazards are cited for a given casualty, the index is ½; that is, an equivalent of ½ casualty per hazard. Within each zone, the average number of casualties per hazard citation was computed and that ratio was applied to the number of citations of each hazard, yielding the equivalent number of casualties for that hazard in that zone. Hazard ratings were then defined in terms of ranges of the criticality index. These ratings are:

5 - highly hazardous
4 - very hazardous
3 - hazardous
2 - not very hazardous
1 - not hazardous

Using this rating scheme, the hazards were ranked within each surrogate transit zone.

Because these rankings are based on surrogates, which are not exact representations of the deepwater port transit zones, and because of the sparseness of the data, some modifications were required to account for peculiarities of the actual situation. This was accomplished by a subjective analysis of the hazards for each zone based upon (1) observations of tanker operations at the Saudi Arabian deepwater port of Ras Tanura, (2) observations made during a transit of the Gulf of Mexico aboard a tanker, (3) paper transits of the Gulf simulating routes expected to be used by the deepwater port tankers, (4) detailed analysis of weather and currents in the Gulf, and (5) analysis of vessel traffic -- recreational boats, fishing vessels, tankers, cargo vessels, and passenger ships -- in the areas of the deepwater port transits.

The hazards to deepwater port tanker transits were subjectively evaluated based upon the information developed from these analyses using the same hazard rating scheme (5=highly hazardous, 4=very hazardous, etc.) as in the casualty data analysis. These hazards were ranked and the results were used in conjunction with the ranking based upon the casualty data to develop the composite hazard rankings shown in table I-1.

It should be emphasized that a high ranking for a situation as a potential hazard does not imply a high probability that the situation will cause a vessel casualty; only that within the set of hazards that can contribute to casualties it is expected to be relatively significant.

The following summarizes the primary hazards in terms of potential effects on deepwater port transit operations.

Table I-1 Composite Hazard Ranking

Straits and Channels		Open Gulf		Safety Fairway		Traffic Separation Scheme		Safety Zone	
Personnel fault	4	Weather	5	Weather	3	Weather	3	Personnel Fault	5
Weather	4	Offshore rigs	3	Offshore rigs	3	Low visibility	3	Weather	5
Vessel traffic	3	Debris	3	Low visibility	3	Personnel fault	2	Low visibility	3
Debris	3			Debris	3	Vessel traffic	2	Moored vessels	3
Depth	2			Personnel fault	2			Currents	2
Low visibility	2			Vessel traffic	2			Vessel traffic	2
Anchored vessels	2			Depth	2			Offshore rigs	2
Currents	2							SPMs	2
Restricted space	2								

Code: 5 = highly hazardous, 4 = very hazardous, 3 = hazardous, 2 = not very hazardous

38

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- Personnel fault in the safety zone - this hazard is inherent in ship operations and is aggravated with respect to the safety zone in cases of moored and moving tankers, low visibility, unusual currents, and lack of conning officer familiarity with own vessel maneuvering characteristics. This hazard is potentially exacerbated during emergency storm conditions when a vessel may be driven far enough out of the safety zone to ground or ram an offshore oil platform. Current storm evacuation plan requirements dictate predesignation of wind and wave thresholds that would trigger port evacuation, but not procedural plans for conduct of such evacuations over a range of credible but difficult scenarios.

- Weather en route to or from the safety zone - this hazard is most severe in the open Gulf. It is somewhat mitigated in the straits because of less exposure time and possibilities of finding a lee or escaping to open sea. It is notable, but not as severe in the fairways and traffic separation schemes due to limited exposure time and the likelihood of not approaching a deepwater port under storm warning conditions.

- Personnel fault in conjuction with decreased visibility, vessel traffic, and offshore rigs (near the deepwater ports) represent a significant hazard in the straits, a moderate hazard in the approaches to the safety zones and a minor hazard in the open Gulf.

- Offshore oil rigs - these objects present a potential hazard along the safety fairways where mobile exploratory operations are conducted. Effective marine advisories of these rig locations are lacking. Since the fairways are not mandatory routes, vessels may take shortcuts that bypass them. Also heavy weather may force a vessel out of the fairway. Consequently, drilling rigs are judged to constitute a significant potential hazard in the regions of the fairways.

- Limited visibility - low visibility can increase the risks of personnel fault accidents, particulary in the deepwater port approaches where more exacting navigation is necessary. This hazard is considered less significant in the open Gulf and straits because of the lower frequency of fog and rain and because of a larger margin for error.

- Floating debris and submerged objects - these hazards have caused a significant number of vessel casualties in the Gulf. Large tankers, such as those that will patronize the deepwater ports, may be less susceptible to the hazard than smaller vessels. However, further analyses may be necessary to determine the extent of this hazard to deepwater port operations.

- Water depth - depth could present a problem in the Straits of Florida, although no instances of tankers grounding in the area were found. The Flower Garden Banks south of the Sabine Pass could present a hazard to tankers en route to SEADOCK that bypass the safety fairway. The depths in the area of the traffic separation schemes and safety zones appear to be sufficient unless a tanker strays from these areas due to heavy weather or some other cause.

- Vessel traffic and moored vessels - there is a significant amount of vessel traffic in the Straits of Florida, which tends to form two distinct traffic streams--

westbound hugging the coast and eastbound further out. In the safety zones, moored tankers and auxiliary vessels would present hazards to tankers approaching the SPMs.

- Aids to navigation - aids to navigation can present hazards in two ways - unreliability or inadequacy and as an object that a vessel can ram. Analysis of casualty data and judgment regarding deepwater port operations led to the conclusion that aids to navigation are not considered to be a potential hazard in either case.

Based upon the predicted oil spill risks for the deepwater ports in terms of frequency of spills, expected amount spilled, and probability of very large spills, it is recommended that a series of analyses be performed to evaluate the potential cost-effectiveness of measures that would mitigate the most significant of these hazards.

II. INTRODUCTION

The U.S. Coast Guard has the responsibility, under the Deepwater Port Act of 1974, for regulation and oversight of deepwater ports off the U.S. Coast. This responsibility includes ensuring that the port designs and operations are environmentally safe. An important aspect of the environmental impact of the ports is the risk of oil spills resulting from tanker casualties.

The study documented in this report, which constitutes a task within a current project for the U.S. Coast Guard to perform marine safety analyses, involved the evaluation of hazards to navigation and an assessment of the oil spill risks from tanker transport operations for two deepwater ports planned for the Gulf of Mexico.

The deepwater ports are the Louisiana Offshore Oil Port (LOOP) and the Texas Offshore Oil Terminal. LOOP is scheduled to begin operation in 1980. The Texas Offshore Oil Terminal, projected for start-up in 1982, is the successor to SEADOCK, whose application has been withdrawn by the sponsors. The name SEADOCK and the SEADOCK characteristics are used in this study to represent the Texas port since it is currently indicated that the Texas port will use the SEADOCK port plans. For analysis purposes, the operation period for SEADOCK will be considered to be the same as LOOP, 1980. Most of the port characteristics used in this study were obtained from the environmental impact statements,[1,2] updated by discussions with LOOP personnel.

As shown in figure II-1, LOOP is located in the Gulf of Mexico about 30 miles west of the Southwest Pass Entrance to the Mississippi River, 13.5 miles off the Louisiana Coast, and SEADOCK is located 20 miles from the Texas Coast, about 26 miles south of Freeport. Diagrams of the port configurations and their approaches are shown in figures II-2 through II-5. Each facility will have a pumping platform complex (PPC) in the open sea, surrounded by single point moorings (SPMs). Entrance to and exit from each of these facilities by vessels will be via a 5- to 6-mile traffic separation scheme (TSS) 2 miles wide, oriented in a southeasterly direction from the PPC, and a 2-mile wide safety fairway oriented in a north-south direction, 63 miles long at LOOP and 58 miles long at SEADOCK. As can also be seen from figure II-1, tankers entering the Gulf of Mexico bound for LOOP and SEADOCK are limited to two basic routes, the Straits of Florida and the Yucatan Channel.

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1. U.S. Coast Guard, Final Environmental Impact/4(f) Statement, LOOP Deepwater Port License Application, Department of Transportation, 1976.
2. U.S. Coast Guard, Final Environmental Impact Statement, SEADOCK License Application, Department of Transportation, 1976.

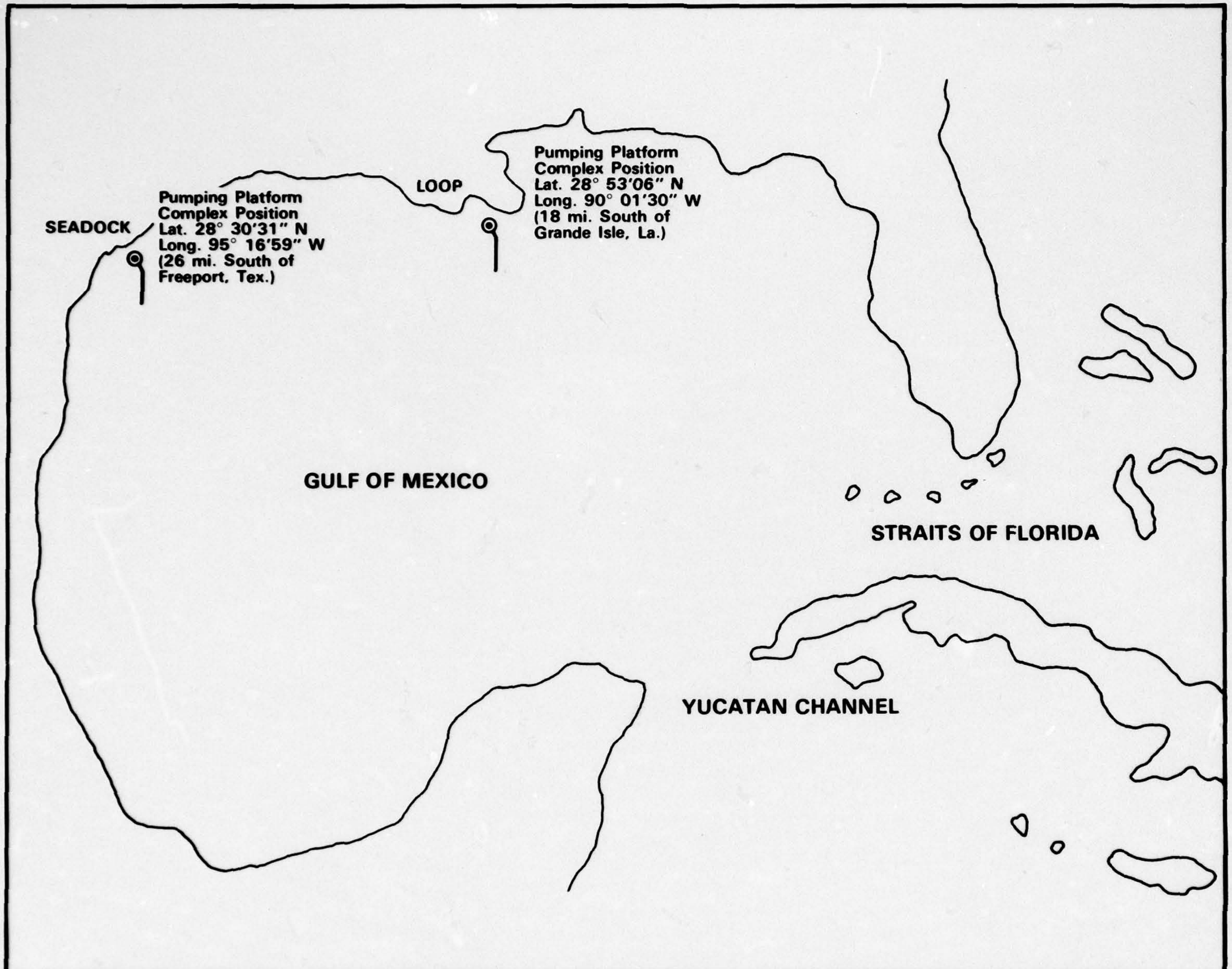
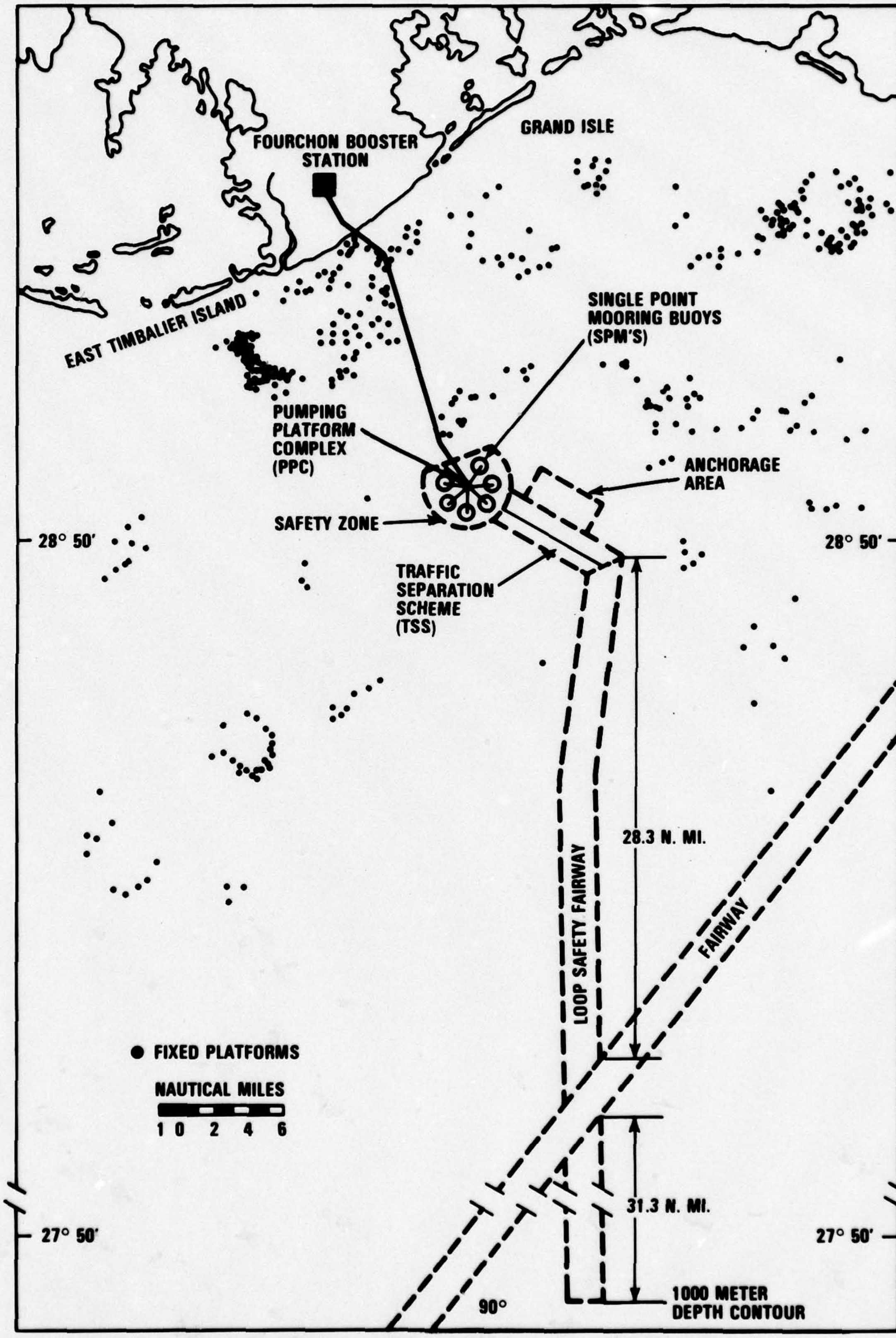


FIGURE II-1. LOOP AND SEADOCK LOCATIONS



SOURCE: U.S. Coast Guard, *Final Environmental Impact/4(f) Statement, LOOP Deepwater Port License Application,* Vol. 1, Department of Transportation, 1976.

FIGURE II-2. LOOP SAFETY ZONE, ANCHORAGE AREA AND TRAFFIC SEPARATION SCHEME

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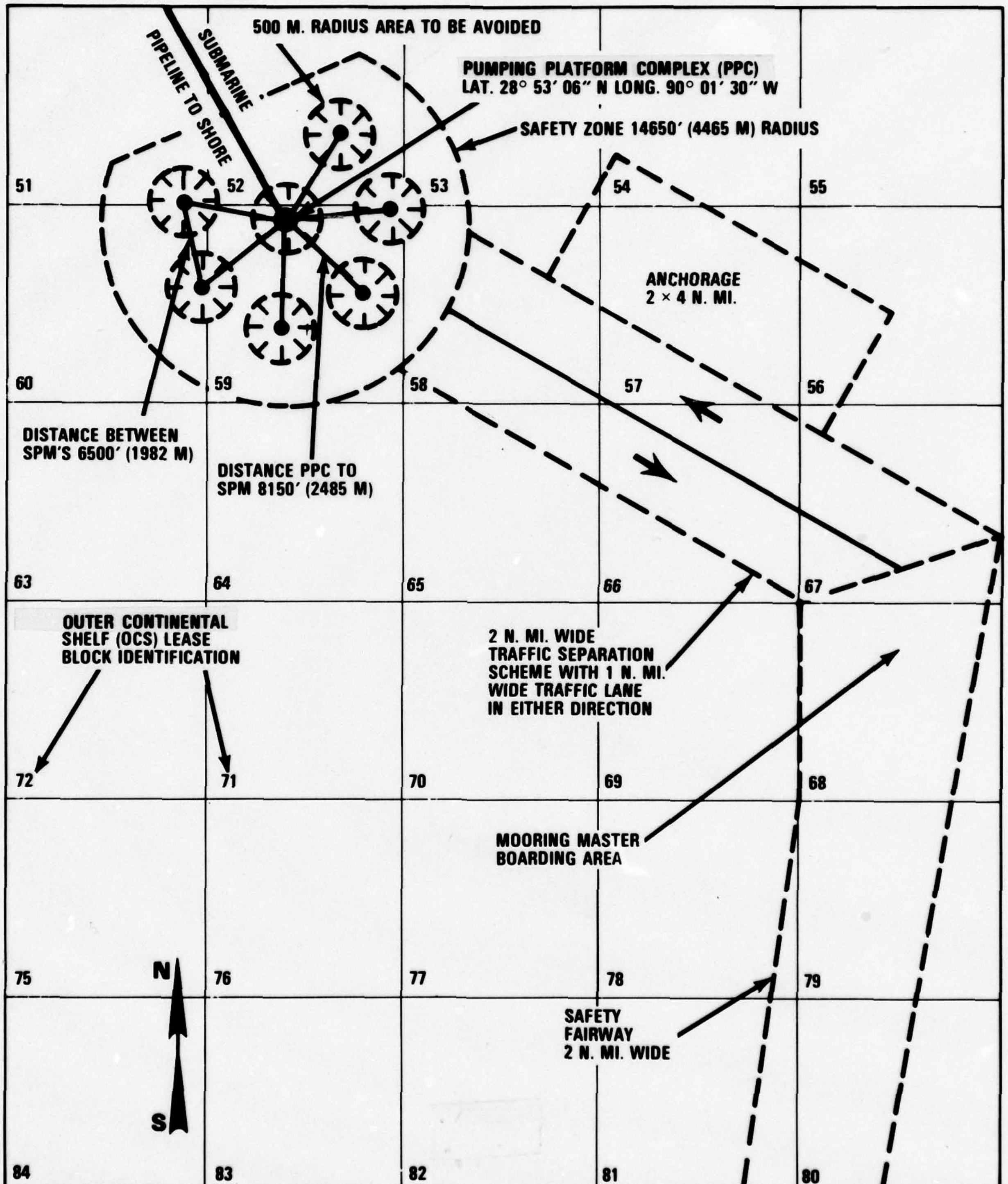

SOURCE: U.S. Coast Guard, *Final Environmental Impact/4(f) Statement, LOOP Deepwater Port License Application*, Vol. 1, Department of Transportation, 1976.

FIGURE II-3. DETAIL OF LOOP SAFETY ZONE, ANCHORAGE AREA AND TRAFFIC SEPARATION SCHEME

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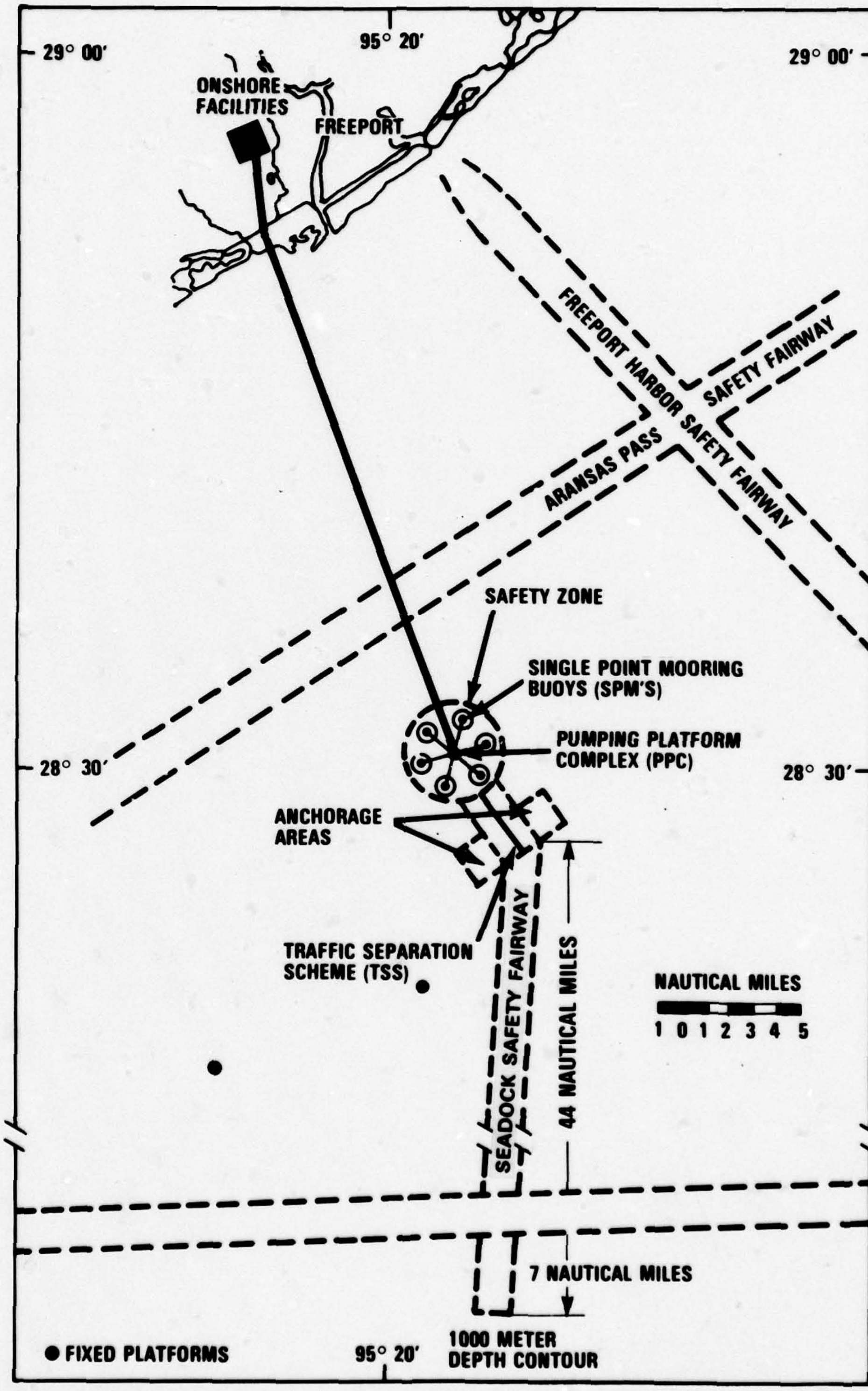
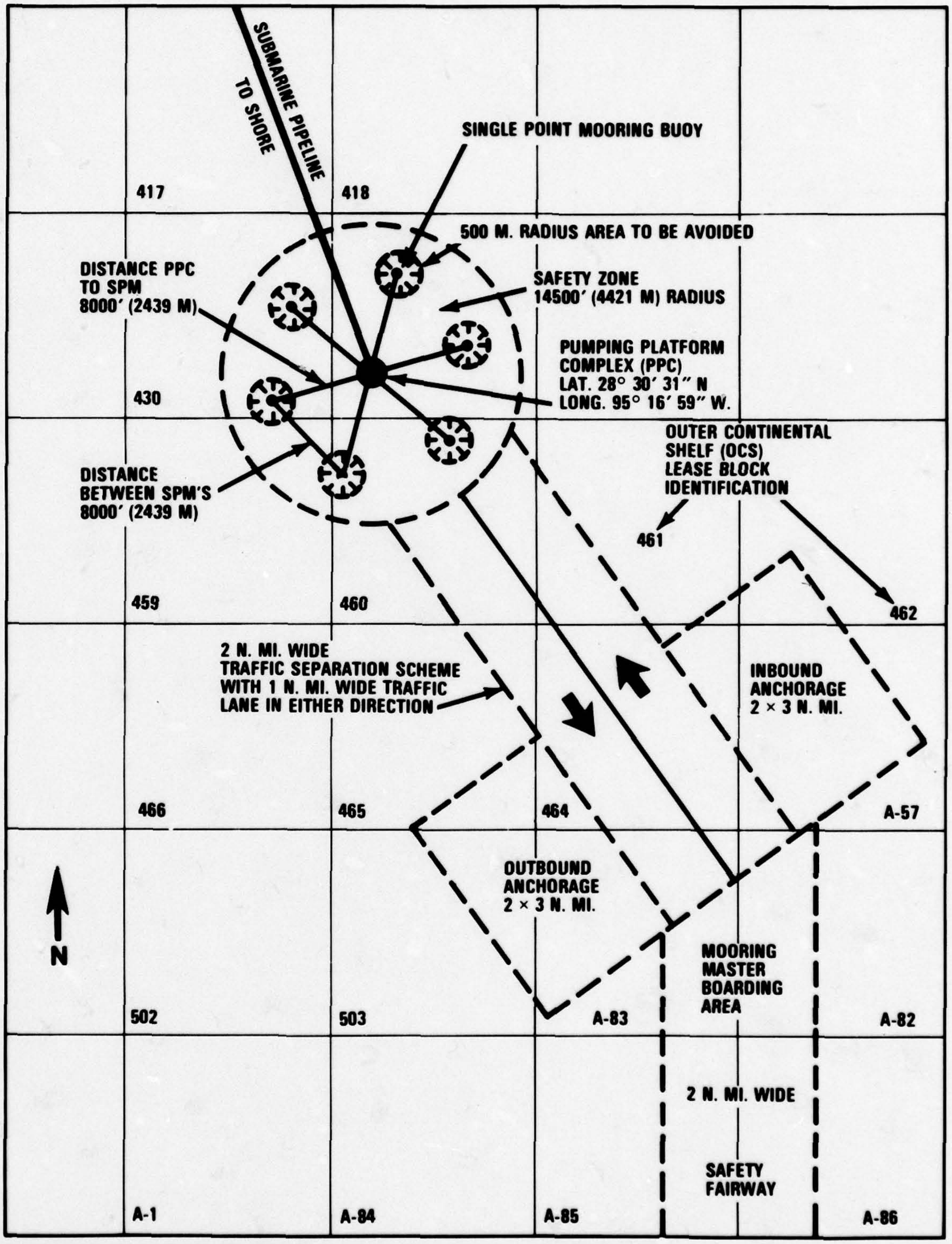


SOURCE: U.S. Coast Guard, *Final Environmental Impact Statement, SEADOCK License Application*, Vol. 1, Department of Transportation, 1976.

FIGURE II-4. SEADOCK SAFETY ZONE, ANCHORAGE AREA AND TRAFFIC SEPARATION SCHEME



Source: U.S. Coast Guard, *Final Environmental Impact Statement, SEADOCK License Application*, Department of Transportation, 1976.

FIGURE II-5. DETAIL OF SEADOCK SAFETY ZONE, ANCHORAGE AREA AND TRAFFIC SEPARATION SCHEME

The projected annual activities for the two deepwater ports for the initial 30 years of operation, as given in the environmental impact statements, are shown in table II-1. Estimates of the sizes of tankers expected to use the ports, obtained from LOOP personnel, are given in table II-2. This report presents the results of an analysis of the hazards to tankers in transit to and from the deepwater ports and a quantitative assessment of the risk of oil spills resulting from tanker accidents over the first 30 years of operation of the ports. The areas of concern for both the hazard and risk probability analysis include the entrances to the Gulf of Mexico (Straits of Florida and Yucatan Channel), the Gulf open sea, the safety fairways, the traffic separation schemes, and the safety zones, which include the SPMs, pumping platforms, and control platforms. Only oil spills resulting from tanker casualties are considered. Spills from transfer operations are the subject of a separate study.

The primary hazards to deepwater port navigation were identified in the study and ranked in order of potential risk. As one of the inputs to this analysis a detailed qualitative evaluation of weather and currents in the Gulf was performed in terms of potential impact on tanker navigation. Vessel traffic in the Gulf was analyzed in terms of fishing vessels, recreational craft, and ocean-going vessels that potentially could affect the tanker traffic enroute to or returning from the deepwater ports.

The hazard identification and ranking method, performed for each transit zone, combined two distinct approaches. The first approach involved a subjective evaluation of navigational hazards based upon a 'paper transit' of the Gulf, personal observations of tanker operations in the Gulf of Mexico and at a deepwater port in the Persian Gulf, and analysis of the weather, current and traffic data for the Gulf area. Second, a detailed analysis of tanker casualty data pertinent to the Gulf transit was performed, resulting in a ranking of hazards by frequency of citations in the data of the hazards in terms of causal factors. A composite ranking was then developed from the two approaches to yield a set of ranked hazards for each transit zone -- straits and channels, open Gulf, safety fairway, traffic separation scheme, and safety zone.

The risks of oil spills in the Gulf resulting from tanker casualties were measured for the 30-year period of operations in several ways.

- The expected number of spills.
- The probability distribution for total volume spilled over the period.
- The probability of an extremely large spill during the period.

TABLE II-1. PROJECTED DEEPWATER PORT ACTIVITY

Year	LOOP		SEADOCK	
	Throughput*	Port Calls	Throughput*	Port Calls
1980	1.3	326	2.5	569
1990	2.6	585	4.4	1,001
2000	3.4	765	4.4	1,001
2010	3.4	765	4.8	1,092

*Million barrels per day.

TABLE II-2. ESTIMATED DEEPWATER PORT TANKER SIZES, 1980

Size*	Vessels/Year	Percentage	Cumulative Percentage
50-100	62	15	15
101-150	79	20	35
151-200	13	3	38
201-250	106	26	64
251-300	107	27	91
301-500	38	9	100
Total	405	100	

*Thousand deadweight tons.

These results were evaluated by 5-year intervals and by casualty type for each deepwater port. The expected number of spills were also evaluated by transit zone.

The estimates were based on historical tanker spill frequency and spill size data, adjusted for application to deepwater port operations.

A number of regression analyses were performed on the casualty data to determine the relationships between casualties and port calls, spills and port calls, volume spilled and volume throughput, and vessel age and casualty rate. The relationship between spills and port calls formed the basis for much of the risk probability analysis.

49 50X

III. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

1. Casualty Data Analysis

The casualty data bases present problems for applications such as this study. The Vessel Casualty Reporting System (VCRS) neither contains data on spill sizes, nor does it indicate the type of location where the casualty occurred -- harbor, pier, at-sea, etc. It does contain causal factors; however, these could be much more useful if the causal sequence were indicated rather than only the individual factors. In addition, the causal factor fields in the data tape often contain extraneous entries such as damage resulting from the accident which makes it difficult to sort out the causal factors.

The Tanker Casualty File contains spill size and location type data. However, it does not contain specific location or causal factors. Consequently, it was necessary for the hazard analysis portion of this study to combine data from the VCRS and Tanker Casualty File. Also, the latest data in Tanker Casualty File are for 1973; consequently, it does not reflect recent trends toward larger tankers. The Coast Guard is currently updating this file.

The Pollution Incident Reporting System also presents problems for risk analysis applications. The data were found to be unreliable in some cases and it was difficult to sort out the spills resulting from tanker casualties from other spill causes.

Analysis of the casualty data by application of regression techniques indicates a strong linear relationship, with a correlation of 0.98, between impact casualties involving tankers and tanker port calls. Similarly, linear relationships were shown to exist between oil spills resulting from tanker casualties and port calls and between volume throughput and volume spilled, with correlation coefficients of .93 and .97, respectively.

No relationship between non-impact casualties and port calls was evident. However, a strong relationship between vessel age and non-impact casualties was discovered (correlation coefficient = .89).

2. Oil Spill Risk Evaluation

The risks of oil spills from deepwater port tanker casualties were estimated for the initial 30-year operating periods of LOOP and SEADOCK. These estimates were based upon historical tanker casualty and exposure data applied to the deepwater port situation. The primary assumptions for the analysis are:

- Tanker operations for deepwater port transits will not differ substantially from those of current tanker operations using standard ports

although certain aspects of deepwater ports such as single point moorings rather than piers and depths large enough to virtually obviate groundings are expected to reduce the casualty risks relative to standard ports.

- o Voluntary rules such as use of the safety fairways will not necessarily be adhered to by the deepwater port tankers.

- o The only effect of time on spill risk will be the increase in the number of deepwater port tanker transits.

- o Spill size distributions are stationary; that is, there is no discernable trend in spill size with time or by ship size (for vessels over 20,000 DWT).

The expected number of spills over the 30-year period for LOOP are 10.9 spills and for SEADOCK, 16.8 spills. Of these it is estimated that about 85 percent will result from impact casualties. Over half of the spills are expected to occur in the straits and channels with another 20 percent in the safety zone. Spill size distributions were estimated from the data by fitting the log normal distribution. It is predicted that over the 30-year period of operations the total amount spilled from vessel casualties will be 53,700 long tons for LOOP and 86,500 for SEADOCK.

The approximate percentages of total expected oil spillage by zone for LOOP are: straits and channels - 40%; Gulf open sea - 21%; safety fairway and traffic separation scheme - 13%; and safety zone - 26%. For SEADOCK, the values are: straits and channels -38%; Gulf open sea - 27%; safety fairway and traffic separation scheme -11%; and safety zone - 24%. These percentages differ between the two ports because of the longer transit distance to SEADOCK.

Although 45 percent of the spills are expected to be less than 500 long tons, the likelighood of very large spills is significant. The probability of a spill at least as large as that of the Amoco Cadiz (220,000 long tons) is estimated at 6 percent, which implies an average time between such spills of 490 years. For a spill at least as large as the Torrey Canyon Spill (109,500 long tons), the probability is 25 percent and the average time between such spills is 120 years.

These probability values imply a significant risk for oil spillage from deepwater port operations. It should be emphasized again that these estimates are based upon fairly conservative assumptions regarding the tanker operations. It is possible that with very strong traffic control and careful selection and training of personnel these risks could be substantially lower.

53 52

Analysis of alternatives to the deepwater ports is beyond the scope of this study. However, two such alternatives were analyzed for the environmental impact statements for LOOP[1] and SEADOCK[2]. The first alternative discussed was the transfer of oil from VLCC's to smaller tankers in the Caribbean and transshipment to the Gulf ports. These analyses indicated that since the existing Gulf ports cannot accept vessel with drafts larger than 40 feet, the average size of the tankers to which the cargo would be transferred would be 50,000 DWT. The average deepwater port tanker is expected to be 275,000 DWT. The results indicated an increase of a factor of about 6 in the expected amount of oil spilled with this alternative relative to the deepwater ports, which is approximately the ratio of the average vessel sizes between the two alternatives. This is consistent with the results shown in this report that vessel casualties and spills are proportional to port calls, which, of course, increase as the average vessel size decreases for the same volume throughput.

Analysis in the EIS reports of a second alternative, deepening existing ports, indicated an increase in risk by a factor of 2 to 7, depending upon the modified depths of the channels. The EIS reports did not assess the spill risks associated with lightering from VLCC's in the Gulf. Since this alternative would result in about the same increase in port calls as in the Caribbean transshipment case, it is likely that it would cause about the same increase in the spill risks from tanker casualties. Further, there would be risks of spillage during transfer.

Consequently, although the risks associated with deepwater port operations may be significant, they do appear to be substantially less than those of the alternatives.

3. Hazard Identification and Ranking

The results of the identification and ranking of hazards to deepwater port transit operations as developed from subjective and analytic analyses are summarized in table VI-6, which is repeated here as table III-1.

Based on the composite hazard ranking and pertinent text of this report, as well as recent research into accident causes and simulator applications, the following are interpreted to be the major hazards of navigation to and from the prospective Gulf of Mexico deepwater ports.

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1. U.S. Coast Guard, Final Environmental Impact/4(f) Statement, LOOP Deepwater Port License Application, Department of Transportation, 1976, Vol. 3, p.B-122.

2. U.S. Coast Guard, Final Environmental Impact Statement, SEADOCK Deepwater Port License Application, Department of Transportation, 1976, Vol. 3, p.B-120.

Table III-1 Composite Hazard Ranking

Straits and Channels		Open Gulf		Safety Fairway		Traffic Separation Scheme		Safety Zone	
Personnel fault	4	Weather	5	Weather	3	Weather	3	Personnel Fault	5
Weather	4	Offshore rigs	3	Offshore rigs	3	Low visibility	3	Weather	5
Vessel traffic	3	Debris	3	Low visibility	3	Personnel fault	2	Low visibility	3
Debris	3			Debris	3	Vessel traffic	2	Moored vessels	3
Depth	2			Personnel fault	2			Currents	2
Low visibility	2			Vessel traffic	2			Vessel traffic	2
Anchored vessels	2			Depth	2			Offshore rigs	2
Currents	2							SPMs	2
Restricted space	2								

Code: 5 = highly hazardous, 4 = very hazardous, 3 = hazardous, 2 = not very hazardous

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Personnel fault in the safety zone may lead to a collision or ramming, which in turn may lead to an oil spill. This hazard is inherent in ship operations and is aggravated with respect to the safety zone in cases of : (a) more tankers in port in transit, (b) fog or rain inhibiting visibility, (c) unusual currents, (d) lack of conning officer familiarity with own vessel maneuvering characteristics due either to unusual vessel design/powering or to unusual loading conditions. This hazard is potentially very great in the event of emergency storm evacuation. Although major storms will be carefully monitored by the deepwater ports, there is some residual risk that a tropical storm or hurricane may veer unexpectely toward one of the ports. Accidents during such storms involve an aggravated risk that a vessel may be driven sufficiently far out of the safety zone to ground and break up with loss of all cargo and bunkers on board. Depending on the number of tankers in port, there may not be sufficient mooring masters available to man all tankers simultaneously. Wave conditions may inhibit transfer of mooring masters to tankers, or worse, injure one of them. Partially unloaded tankers may display unusual maneuvering characteristics, especially when getting underway at slow speed in high winds/waves. Ship masters may, with or without the concurrence of the port manager, decide to get underway without a mooring master if they think it necessary to save their ships. Current storm evacuation plan requirements dictate predesignation of wind and wave thresholds which would trigger port evacuation, but not procedural plans for the conduct of such evacuations over a range of credible but difficult scenarios.

Adverse weather enroute to or from the safety zone may lead to a control/propulsion breakdown and ultimate breakup of the tanker, or to limited hull damage, or to collision or ramming with loss of one or two tankloads of cargo. This danger is greatest in the open Gulf due to the duration of storm exposure. Adverse weather is severe in the straits, but is mitigated by lesser exposure and by possibilities of finding a lee or of escaping to open sea. It is notable, but not severe in the safety fairways and the traffic separation schemes due to limited exposure and the likelihood of not approaching a deepwater port under storm warning conditions. Personnel fault in conjunction with decreased visibility, vessel traffic, and offshore rigs (near the deepwater ports), represent a significant hazard in the straits, and a moderate hazard in the approaches to the safety zone and a minor hazard in the open Gulf. There is a baseline set of navigational hazards in that a single major watchstander error, or some small number of joint lesser errors, can lead to a ramming, grounding, or to a nearly unavoidable collision situation. There are numerous combinations of situational factors that can induce such errors. The fault tree analysis presented in this

report indicates very little protective redundancy in marine operations (numerous OR gates over multiple hazards with few AND gates throughout the trees and especially lacking AND gates at high levels in the trees.) The ship navigation system is highly dependent on farsighted anticipation of potential hazards by the conning officers. When hazards arise, the ship operating system relies heavily on an officer's early detection of the hazard, prompt and accurate evaluation and decision, and timely effective corrective action as needed. The degree of safety observed in ship operations is a tribute to the performance of mariners generally, given the basic human frailties, the numerous opportunities for error, and the limited extent of sensor/analysis/decision redundacy in the operating system. The baseline risk increases with increased traffic density and directional variability in a restricted seaway and especially with the proportion of that traffic composed of unlicensed operators such as recreational boaters and fishermen. The risk is also increased with shoal/obstruction uncertainties which are indicated as severe for westbound traffic from Fort Pierce/ Mantanilla Shoal to Miami/Providence Channel Entrance, and somewhat less for eastbound traffic in the same area.

The risk of ramming offshore rigs is present and potentially severe along those portions of Gulf safety fairways where mobile exploratory drilling operations are now conducted or will be during the operating life of the deepwater ports. The hazard is negligible elsewhere. Superficially, the problem is solved by designated safety fairways in which rig emplacement is prohibited. These fairways are not mandatory as ship routes, however; they are not necessarily economical routes; and, depending on the shiphandler's knowledge and judgment regarding rig activity, the perceived risk of shortcutting the fairway routes may be low. Finally, heavy weather may preclude ability to remain in fairways even given diligent effort to do so. These factors, combined with lack of effective mariner advisories of rig movements (outside of ten miles off the deepwater port approach fairways), necessitate rating this as a potentially severe hazard.

The risk of personnel fault accidents is increased by fog or rain, which constitutes a significant hazard in the deepwater port approach fairways. Although fog or rain are not uncommon in the traffic separation scheme and safety zone, the hazard is mitigated by slow speed, mooring masters with detailed local knowledge, and the availability of vessel traffic service. These factors do not apply in the approach fairways. Because fog and rain are less common in the open Gulf and the straits, the visibility hazard is less in these zones. Where a visibility hazard exists, the risk of accident is increased by failure to reduce speed appropriately, by low capability of radar or other shipboard navigation

equipment and/or poor maintenance of such equipment, by failure to utilize all possible means of lookout, and by lack of current, specific watchstander skills in reduced visibility/ restricted water shiphandling.

Floating or submerged debris, depending on its size and material (for example, wrecked steel hull sections or wooden logs) may cause hull damage or it may damage or disable a vessel's propulsion or steering, leading to increased risk of grounding or structural failure. There were six instances recorded of debris rammings by U.S. registered tankers from 1969 through 1973. Five of these were coastal and one occurred in the open sea. There were ten such casualties in the Gulf of Mexico (excluding inshore areas) from 1969 through 1977 involving tankers, freighters, and other vessels. Large tankers, due to their hull strength and to the depth of their screws and rudders below the surface, may be less susceptible to this hazard than are smaller vessels with shallower drafts. Nonetheless, the hazard requires some further precautionary measures and the development of a better appraisal of the extent of the hazard than is currently available.

Considering the sizes of the tankers expected to use the deepwater ports, explicit care was taken to examine the water depth hazard. Isolated water depth hazards do exist in the Straits of Florida, in the vicinity of parts of the safety fairways (the Flower Garden Banks south of the Sabine Pass), and shoreward of the deepwater ports. Normally prudent seamanship and planned deepwater port operating procedures appear sufficient counters to this hazard except in the event of one of the above hazards operating to cause loss of effective and intelligent ship control. The only offshore tanker groundings reported in the Gulf of Mexico from 1969 through 1977 were well shoreward from the Texas deepwater port near Sabine Pass or near the Florida west coast, as shown in figure VI-24.

Being a primary responsibility of the U.S. Coast Guard, aids to navigation were also examined explicitly. These aids generally serve to help prevent accidents but can also constitute a ramming hazard. Tanker casualty data studied indicated rammings of aids to navigation only in two harbor casualties and reliability/adequacy involvement only in one coastal and two harbor casualties (see table VI-2). There were four such involvements listed in table VI-4 for Gulf of Mexico vessel accidents during 1969 through 1977. All factors discussed above as significant hazards have more documented accident involvement and also more potential as hazards based on actual and "paper" transit judgments. Reliability and adequacy of navaids were judged to be "not hazardous" throughout the Gulf of Mexico transit area, as was the potential of ramming aids to navigation.

B. Recommendations

To allow more efficient use of the casualty data for risk analysis, several improvements in the Vessel Casualty Reporting System are recommended:

- Add spill size information.
- Add location type.
- Reorganize causal data so that they are more useful for casualty cause analysis.

As pointed out in the discussion on fault trees (section VI.A.4), trees such as those presented in appendix D could prove useful in reorganizing the causal data portion of the VCRS to provide a more structural basis for causal analyses. This is particularly important for personnel fault casualties, which represent a significant proportion of the tanker casualties.

This study has shown that there is significant likelihood of very large oil spills from deepwater port tanker transits as well as a large expected total amount of oil spilled over the first 20 years of operations. Further, specific hazards to navigation in the varous transit zones were identified and evaluated. It is recommended that measures for mitigating the primary hazards be evaluated in a cost-benefit framework to determine the optimal means of reducing the oil spill risks.

(59) (58)

IV. DATA SURVEY AND ANALYSIS

A. Vessel Casualty Data

Casualty data for this study were obtained from three different data systems -- the Vessel Casualty Reporting System, the Pollution Incident Reporting System, and the Tanker Casualty File. This section briefly describes the contents, as well as some of the limitations, of each of these systems. The specific problems of data completeness and accuracy which are a result of data collection and recording processes are not discussed here as they were analyzed in detail in the report of another task of this project.[1] Instead, only the data problems which are specific to the deepwater port analysis are discussed. While this section discusses the completeness of the Tanker Casualty File and the Vessel Casualty Reporting System, its emphasis is toward patterns of incompleteness rather than incompleteness as a result of the data collecting process.

1. Vessel Casualty Reporting System (VCRS)

Since 1963 the Information and Analysis Branch of the U.S. Coast Guard has kept records of vessel casualties in U.S. waters and vessel casualties involving U.S. vessels around the world. These records form the Vessel Casualty Reporting System (VCRS). A casualty is defined as any mishap which results in the following:

a. "Actual physical damage to property in excess of $1,500;

b. Material damage affecting the seaworthiness or efficiency of a vessel;

c. Stranding or grounding;

d. Loss of life, or

e. Injury causing any person to remain incapacitated for a period in excess of 72 hours; except injury to harbor workers not resulting in death and not resulting from vessel casualty or vessel equipment casualty."[2]

The VCRS data have been divided into three major categories: (1) vessel casualties, (2) death and/or injury occurring at the time of a vessel

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1. PRC Systems Services Company, Survey of Marine Casualty, Pollution, and Traffic Data Bases, prepared for the U.S. Coast Guard (to be published).
2. Information and Analysis Branch, U.S. Coast Guard, Statistics of Casualties, published annually, (Washington, D.C.)

casualty, and (3) death and/or injury related to vessel operations but not involving a vessel casualty. For purposes of this study, we are concerned with (1) vessel casualties, and (2) death and/or injury occurring at the time of a vessel casualty. The casualties are accidents satisfying at least one of conditions a, b, or c listed above.

Of particular importance to this study is that the cause of a casualty is recorded in the accident report. A ship master or investigating officer may record as many as four accident causes or factors. These "causes" are selected from a standard list, which limits specificity. They can in some cases be self-serving, such as "fault of other vessel." Moreover, these causes do not, in most cases, allow one to determine the chain of events which led to the casualty. Nonetheless, this data base is the only automated system available which provides any type of causal information. These causal data were useful in the hazard ranking discussed in section VI of this report.

The location codes used in these data are specific enough to determine whether a casualty occurred in a given port system (defined in section IV.C). However, these codes are not specific enough to detemine whether the casualty occurred in a harbor, pier, entrance, or along the coast. As a result, enough information can be gleaned to calculate relationships between casualties and port calls (port calls were obtained from Waterborne Commerce data) but not enough information to determine relationships between types of casualties and the specific area (pier, harbor, etc.) where that casualty took place. Later in this report the importance of being able to perform these calculations and establish these relationships is shown.

One of the drawbacks to this data system is that it is not possible to determine the amount of vessel oil spillage. Spill information is given as light, moderate, or heavy. A dollar figure is given for cargo damage; however, this is not sufficient information to analyze oil tanker spills.

Another problem in using these data is that both vessel age and gross tons are coded in groups as opposed to giving actual age and gross tons. This type of coding does save space for computer purposes but a great deal of information is lost as a result. This is a particular problem for evaluations based on size since all vessels of size greater than 15,000 gross tons are grouped together.

The data from this system which proved to be most valuable in this analysis were casualties by port system and the reported causes of casualties.

2. Pollution Incident Reporting System

In 1971, as part of the Marine Environmental Protection Program, the U.S. Coast Guard began collecting data for the Pollution Incident Reporting System (PIRS). PIRS was established to collect reports of discharged oil and other hazardous materials into U.S. waters. In addition to actual discharges, PIRS is also designed to record potential spillage of oil and hazardous materials. A potential spill is recorded if a casualty occurs that could have resulted in a spill, but did not. The spill amount recorded in these cases is generally the total amount carried in the vessel. Potential spills were not included in the data used for this study, since they do not reflect a realistic measure of spill risk.

The analysis of deepwater port hazards and risk did not utilize a great deal of the PIRS data. This data system records discharges from marine, land, and non-transportation related facilities, land vehicles and pipelines, as well as vessels. The vessels include tankships, tank barges, dry cargo ships, tugboats, as well as fishing, passenger, recreational, combatant, public, and Coast Guard vessels. For the deepwater port study, only tankship data were needed.

The data were further reduced based on the cause of pollution. The PIRS system has six basic categories of causes: (1) structural failure or loss, (2) equipment failure, (3) personnel error (unintentional discharge), (4) intentional discharge, (5) other transportation casualty, and (6) natural or chronic phenomenon. Because the deepwater port analysis is only concerned with vessel casualties, only the structural failure or loss category was used.

Each cause category is subdivided into immediate cause and contributing factor. The immediate causes included under "structural failure or loss" are (a) hull rupture or leak, (b) tank rupture or leak, (c) transportation pipeline rupture or leak, (e) container lost intact, (f) well blow-out, and (h) other structural failure. Only (a), (b) and (h) were used for this study.

The next reduction in data was based on a combination of the Contributing Factors and Type of Operation categories. Table IV-1 presents a list of factors and operations used for this selection. Factors A-H, and R were used with all operations listed. Factors I-Q were used with operations 64-69.

The final data reduction was based on the material spilled. All types of oil spillage were included. Materials classified as "hazardous substances other than oil" were not used.

This series of reductions was designed to draw from the data incidents involving oil-carrying tanker casualties occurring during operations which

TABLE IV-1. CONTRIBUTING FACTORS FROM PIRS DATA WHEN THE CAUSE CATEGORY IS STRUCTURAL FAILURE OR LOSS

A. Collision
B. Grounding
D. Capsizing/Overturning
E. Sinking
F. Other Casualty
G. Adverse Weather Or Sea Conditions
H. Earthquake Or Other Natural Disaster
I. Minor Damage
J. Material Fault
K. Design Fault
L. Personnel Error - Improper Maintenance
M. Personnel Error - Overpressurization
N. Other Personnel Error
O. Corrosion
P. Sand Cutouts
Q. Other Or Unknown
R. Ramming

TYPE OF OPERATION USED IN SELECTING PIRS DATA

00. No Operation In Progress
61. Transfer Or Shifting Of Liquid Within Vessel
62. Repair, Modification, Or Maintenance Of Vessel
63. Repair, Modification, Or Maintenance Of Equipment
64. Mooring At Dock
65. Departing From Dock
66. Moored (Not Engaged In Any Operation Listed Above)
67. Anchored (Not Engaged In Any Operation Listed Above)
68. Underway
69. Lightering
80. Other Vessel-Related Operation
99. Unknown Operation

were neither land related nor transfer related. As can be seen from the cause and operation categories, it is difficult to determine with absolute certainty which incidents actually resulted from vessel casualties. The incidents included were those judged most likely to fit the description of casualties needed for this analysis. After the data were reduced, the number of oil spill incidents remaining for the period January 1973 through September 1977 was 198.

These data were of only limited value in the deepwater ports study. One problem with these data is that they cover only U.S. waters, thus limiting the ship sizes to those that can navigate the American ports (except for some lightering activity within Delaware Bay). Further, the casualty categories discussed above do not lend themselves to analysis of causes, which was necessary for the hazard ranking effort. Also, the data contained a significant number of errors in classification of spill causes, location, vessel type, and other parameters.

The primary use of these data was to determine the relationship between number of spills and port calls and between amount spilled and volume throughput. These very significant relationships are discussed later in section IV.B of this report.

In spite of drawbacks in the PIRS data, it is the only data base that contains the appropriate spill location information to allow the number and volume of spills to be computed by port system.

3. Tanker Casualty File

The Tanker Casualty File (TCF) is a computerized data base designed by the U.S. Coast Guard and collected from vessel casualty reports published by Lloyd's of London. These data contain information regarding tanker casualties including location of casualty, amount of spillage, extent of vessel damage, and vessel specification, i.e., name, flag, tonnage, and year built. Tanker casualties from around the world are included in these data. At the present time, data are only available for the years 1969-1973. The 1974-1976 data have been collected, but have not been edited.

This data system has a number of advantages over the other two casualty files used. The TCF is the only worldwide vessel casualty and vessel spillage data base without severe restriction on the types of casualties included (i.e., another worldwide data base[1] contains only vessel casualties which resulted in total losses).

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1. Generated by the Liverpool Underwriters Association.

In addition, the Tanker Casualty File is the only data base which records the specific area where the casualty occurred, i.e., pier, harbor, entrance, coastal, or open sea. It is possible to obtain this information from PIRS, but only after plotting latitude and longitude.

Some of the problems involved with using these data are that they are not current -- only 1969-1973 data are available -- and, secondly, the exact location of a casualty cannot be determined. This data system divides the world into 22 segments and indicates where the casualty took place based on these 22 codes. It also indicates whether the location is a pier, harbor, entrance, etc. Therefore, the data can indicate, for instance, that a casualty took place at a pier in a Gulf of Mexico port, but is not more specific. The system would not indicate that a casualty took place at a pier in New Orleans, for example.

A more significant problem with these data is that whenever the amount of oil spilled is not known, but it is known that a spill did occur, the amount is calculated by taking the average spill size under 500 long tons for the appropriate casualty type and assigning that value to the spill size parameter. This creates a problem in attempting to fit a distribution to the volume spilled because a disproportionate number of spills tend to congregate at the average value. The data base does indicate when such a method was used to determine spill size. Therefore, the calculated spills were taken out of the data for the purpose of fitting spill size distributions, as is discussed in more detail later in this report.

The information in this file proved to be valuable in analyzing spill number and spill size distribution for the deepwater port area. In addition, a relationship between the specific areas given in this data base and the five deepwater port transit zones was used in estimating spill rate and hazard ranking by zone discussed in sections V and VI, respectively.

B. Vessel Traffic Data

1. General Gulf Traffic

One of the hazards tankers coming into the deepwater ports must be concerned with is other traffic. Along the deepwater port routes tankers encounter other ocean-going vessels, fishing boats, and pleasure boats. This section discusses that traffic.

a. Ocean-Going Traffic

To provide an estimate of the ocean-going traffic in the Gulf, historial port calls provided by Waterborne Commerce of the U.S.[1] was used. It was necessary to make certain assumptions about the traffic routes used by these vessels since origination and destination points of this traffic were not available at this writing.[2] Most of these assumptions are the same ones used in the Final Environmental Impact Statement[3] for LOOP and SEADOCK. These assumptions are as follows:

- Vessels less than 18-foot draft will be excluded from ocean-going traffic counts.
- All passenger and key cargo vessels over 18-foot draft make two port calls within the Gulf.
- For passenger and key cargo vessels over 18-foot draft, 60 percent use the Florida Straits in and out of the Gulf and 20 percent use the Florida Straits on one leg of the voyage.
- All tankers make one port call per trip in the Gulf.[4] Fifty percent of the tankers use the Straits of Florida and 50 percent use the Yucatan Channel.

The result of these assumptions can be seen in table IV-2. In 1976, it is estimated that 13,905 ocean-going vessels traversed the Straits of Florida and 8,540 used the Yucatan Channel. This implies that, on the average, 38 vessels per day used the Straits of Florida and 23 per day used the Yucatan Channel. Each of the ports and their relation to the paths to LOOP and SEADOCK can be seen on the map in figure IV-1.

b. Fishing Boats

Fishing boats can also present a hazard to tanker operations in the Gulf. The 1976 fishery statistics[5] lists the distances offshore at which the

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1. U.S. Army Corps of Engineers, Waterborne Commerce of the United States, (Washington, D.C., 1969-1976), Volume 2.
2. This information is part of the Census Bureau Data Base Statistics, Washington, D.C.
3. U.S. Coast Guard, Final Environmental Impact Statement LOOP Deepwater Port License Application prepared by Arthur D. Little, Inc. (Washington, D.C., 1976.)
4. Ibid. Volume 3, p. B-133.
5. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fisheries of the United States 1976. (Washington, D.C., 1977), pp. 8-10.

Table IV-2. Port Calls for Tankers, Dry Cargo & Passenger Vessels and Towboats & Tugboats in the Gulf of Mexico in 1976

Port	Port Calls: Tankers	Dry Cargo & Passenger	Tows & Tugs
Charlotte Harbor	27	34	3
Tampa Harbor	479	770	154
Panama City Harbor	2	55	-
Pensacola Harbor	44	110	-
Mobile Harbor	109	781	7
Pascogoula Harbor	264	106	28
Gulfport Harbor	-	232	-
Calcacieu River	282	144	2
Sabine-Neches Waterway	1,399	367	8
Houston Ship Channel	1,416	2,037	23
Texas City Channel	637	35	4
Galveston Channel	76	668	4
Freeport Harbor	317	72	2
Corpus Christi Shipping Channel	651	295	18
Brazos Island Harbor	65	79	-
Port of New Orleans	984	3,156	64
Total	6,752	8,941	317
Number of Trips Through: Straits of Florida	6,752[1]	7,153[2]	0
Yucatan Channel	6,752[1]	1,788[2]	0
Total Trips Through Either Straits of Florida or Yucatan Channel	13,504[3]	8,941[4]	0[5]

[1]Assuming 50% of tankers use Florida Straits and 50% use Yucatan Channel.

[2]Assuming 60% of passenger and dry cargo vessels use the Florida Straits in and out of the Gulf and 20% use the Straits of Florida on one leg of the voyage.

[3]Each tanker makes one port call in the Gulf. For each port call vessel comes into and goes out of Gulf. Therefore, multiply port call by 2.

[4]All passenger and dry cargo vessels make two port calls within the Gulf. So divide number of port calls by 2 for number of trips into Gulf; multiply remainder by 2 to account for trip out of Gulf.

[5]Tows and Tugs are not expected to leave the Gulf. The large Tows and Tugs are, however, a hazard when they go far enough into the Gulf.

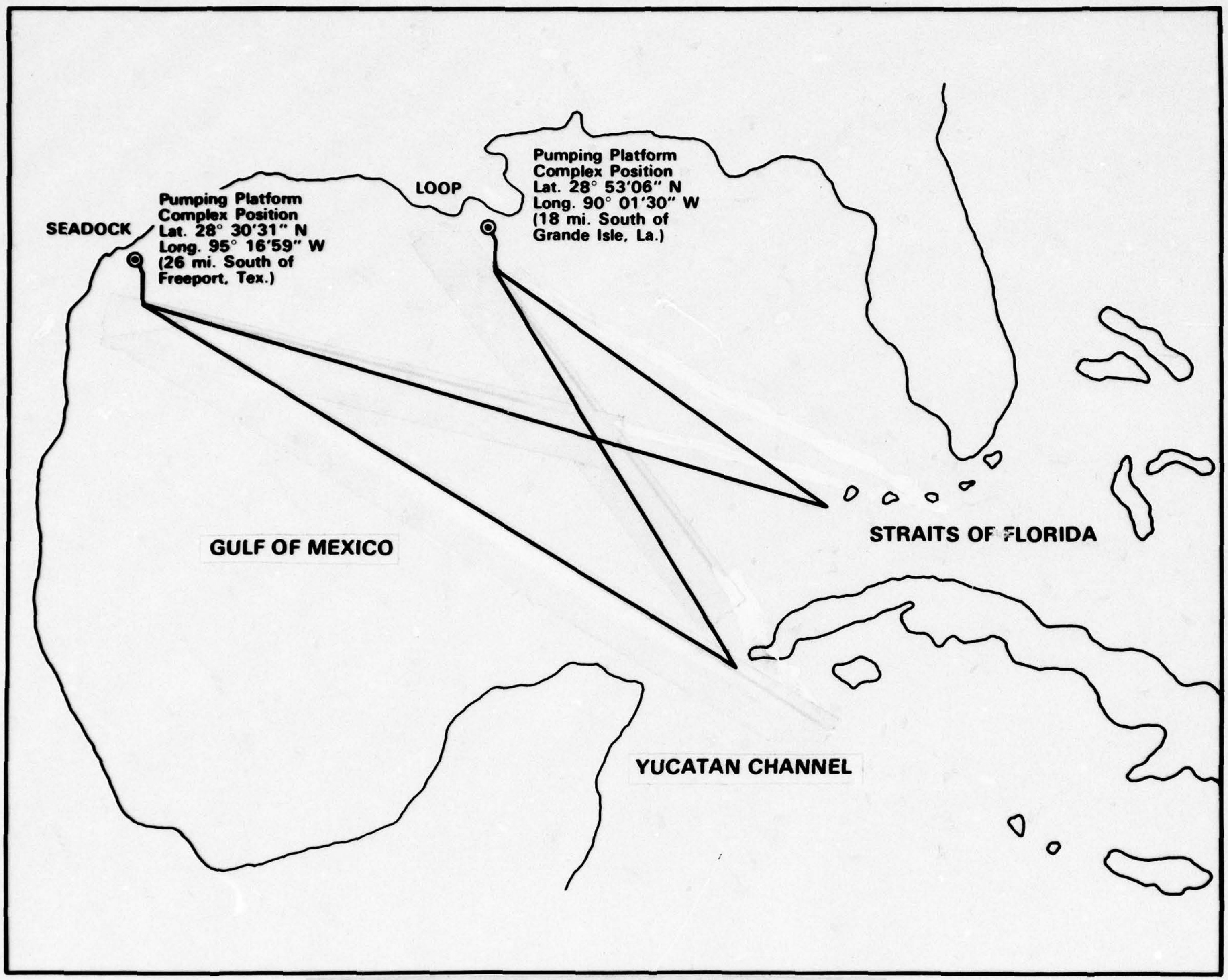

FIGURE IV-1. U.S. PORTS IN GULF OF MEXICO

(68) (67)

various species were landed, categorized by 0-3 miles, 3-12 miles, 12-200 miles, and international waters. Based upon the Fishery Statistical Digest of 1974,[1] the primary fish and shellfish caught in the Gulf -- comprising 95 percent of the pounds landed -- are menhaden, mullet, croaker, mackerel, shrimp, blue crab, oysters, and unclassified fish for bait, reduction, and animal food. Table IV-3 presents the distances offshore at which these species were caught. Figures for shrimp and menhaden were given for the Gulf region; the other fish listed were not categorized by region. It is clear from the table that virtually all fishing activity except shrimping occurs within 12 miles of shore. Since the deepwater port tanker operations are to occur beyond this distance, the primary concern for this analysis is the shrimping activity.

The National Marine Fisheries Service publishes monthly Gulf Coast shrimp data.[2] These data are broken down by area, zone, and fathoms in the Gulf. Table IV-4 shows the number of trips made by shrimp boats in 1976 by area. Within each area are a number of zones. The map in figure IV-2 shows 15 of these zones including the 8 zones which are intersected by routes to LOOP or SEADOCK. The National Marine Fisheries Statistics gives the number of shrimp boat trips by depth of water in fathoms within each zone. By plotting the tanker routes to LOOP and SEADOCK on a chart showing water depth, it is possible to estimate the amount of shrimp boat traffic which may be a hazard to deepwater port tankers. Table IV-5 shows the number of shrimp boat trips along the deepwater port routes during 1976. The total is 6,848 trips per year or an average of 18.8 trips per day. The most congested zone is 19 which is the zone in which SEADOCK is located. In zone 19, in water greater in depth than 10 fathoms, the total number of shrimp boat trips was 3,432, averaging to 9.4 per day. The most congested month was August which averaged 37 trips per day in all zones listed. This included an average of 22.0 trips in zone 19. Shrimp boats are obviously a hazard with which deepwater port tankers must be concerned.

c. Pleasure Boats

Tankers to the deepwater ports must also view pleasure boats as a potential hazard. Because relatively few pleasure boats go far enough

1. U.S. Department of Commerce, National Oceanic and Atmospheic Administration, National Fisheries Service, Fishery Statistics of the United States, 1974, Statistical Digest No. 68, pp. 17-19.
2. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Gulf Coast Shrimp Data. (Washington, D.C.), January and December 1976.

Table IV-3. Distance Off U.S. Shores Fish Were Caught (Thousand Pounds)

	Distance off U.S. Shores Fish Were Caught (Thousand Pounds)					
	0-3 Miles	3-12 Miles	12-200 Miles	International Waters	Total	Percentage Within 12 Miles
Menhaden[1]	1,068,494	169,285	-	-	1,237,779	100
Shrimp[1]	70,853	32,482	97,842	16,662	217,839	47.4
Mullet[2]	30,265	204	20	6	30,495	99.2
Croaker[2]	19,179	11,345	1,070	-	31,594	96.6
Mackerel[2]	6,163	13,734	3,116	-	23,013	86.4
Oysters[2]	54,391	-	-	-	54,391	100
Blue Crab[2]	112,797	166	189	-	113,152	99.8
Unclassified[2]	239,759	95,920	18,020	1,534	355,233	94.5

1. Figures are for Gulf only.

2. Figures are for all U. S. Waters.

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Services, Fisheries of the United States, 1976 (Washington, D. C., 1977) page 8.

69

Table IV-4. Estimated Number of Trips by Shrimp Fishing Boats in the Gulf of Mexico by Area, 1976

Area	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Sanibel-Tortugas	772.0	910.2	891.0	776.6	500.2	457.5	222.2	189.0	238.3	308.5	594.1	967.6	6,827.2
Apalachicola	462.0	411.1	870.1	1,605.5	1,784.3	1,384.0	1,066.2	814.4	1,030.0	1,520.8	1,128.5	615.3	12,692.2
Pensacola-Mississippi River	315.9	136.4	187.8	321.8	1,135.3	7,270.9	6,047.3	3,171.4	4,968.1	4,051.1	1,745.7	904.0	30,255.7
Mississippi River-Texas	1,574.0	1,401.6	1,165.9	1,416.6	36,628.2	44,948.3	14,752.6	18,468.6	19,071.4	19,955.4	7,758.5	4,335.0	171,476.1
Texas Coast	692.8	982.4	1,514.3	2,908.5	8,051.9	8,952.0	6,127.7	8,277.6	11,022.2	8,007.2	3,428.2	1,244.7	61,209.5
High Seas off Mexico W. of 97°	270.3	353.9	233.1	139.0	99.7	4.9	-	-	-	-	-	-	1,1009
High Seas off Obregon & Campeche	160.0	164.4	273.8	247.0	152.4	35.4	-	-	-	-	-	-	1,033.0
Atlantic Cont.	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4
Total	4,247.0	4,360.0	5,136.0	7,416.0	48,352.0	63,053.0	28,216.0	30,921.0	36,330.0	33,843.0	14,655.0	8,067.0	284,595.0

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Gulf Coast Shrimp Data (Washington, D.C., January-December 1976).

70

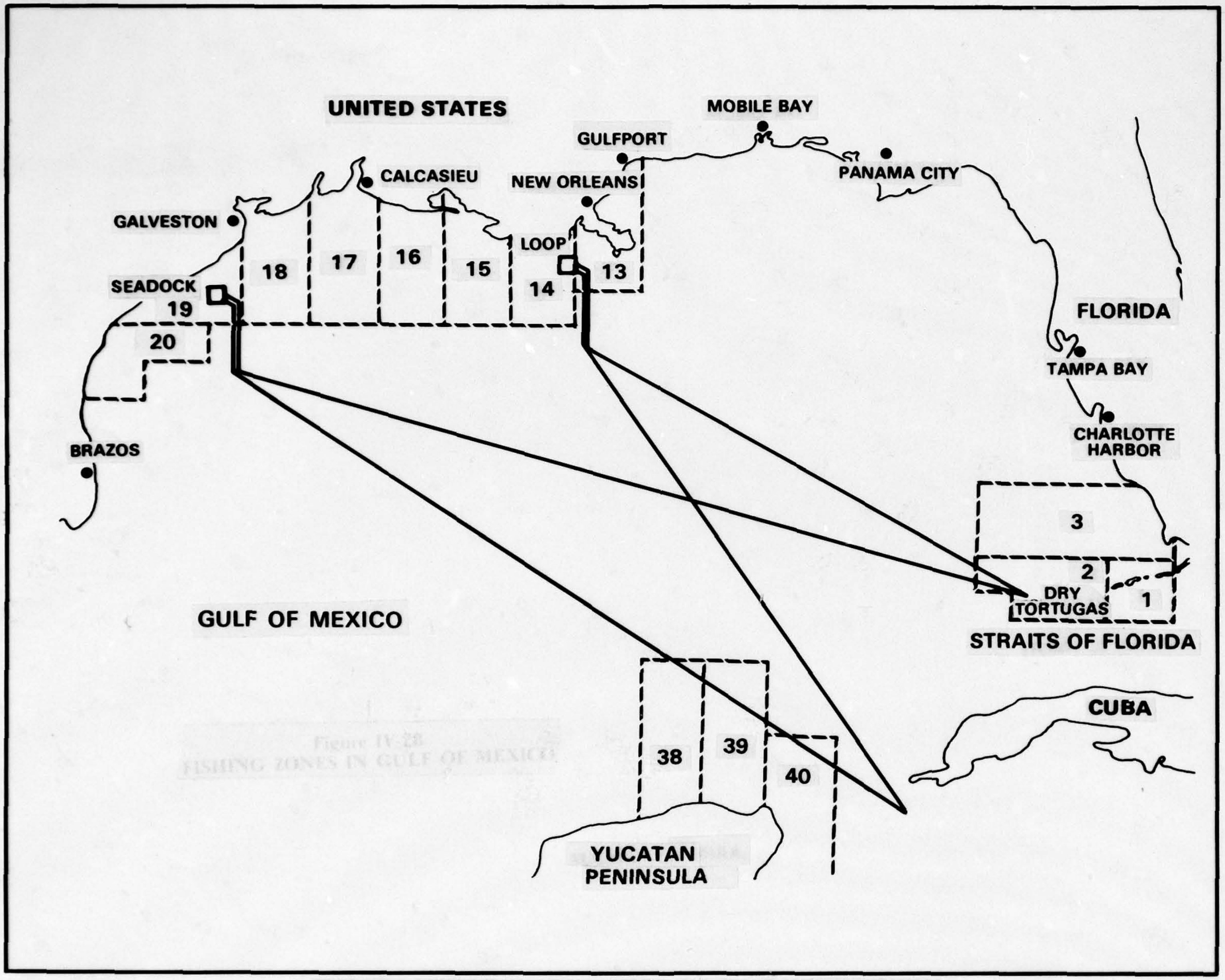

FIGURE IV-2. FISHING ZONES IN GULF OF MEXICO

Table IV-5. Estimated Number of Shrimp Boat Trips in Areas Intersected by Paths to LOOP and SEADOCK

Zone	Fathoms Greater Than	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2	30	-	31.0	3.0	14.0	8.3	5.5	0.8	-	-	0.8	0.1	-	63.5
13	15	55.9	132.6	98.6	114.7	70.0	83.4	171.3	227.9	226.7	105.9	149.1	144.2	1,580.3
14	10	127.0	82.6	30.9	82.3	17.8	69.8	203.3	69.1	96.0	4.4	24.6	9.2	817.0
18	20	41.6	3.9	30.5	0.4	56.4	6.0	86.3	166.9	139.1	224.3	129.6	69.7	954.7
19	10	83.0	92.2	180.3	154.3	6.1	117.0	638.8	683.2	503.1	432.2	379.7	162.3	3,432.2
38	40	-	-	-	-	-	-	-	-	-	-	-	-	0.0
39	25	-	-	-	-	-	-	-	-	-	-	-	-	0.0
40	100	-	-	-	-	-	-	-	-	-	-	-	-	0.0
Total		307.5	342.3	343.3	365.7	158.6	281.7	1,100.5	1,147.1	964.9	767.6	683.1	385.4	6,847.7

Source: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Gulf Coast Shrimp Data, (Washington, D. C., January-December, 1976).

72

offshore to be out of sight of land, the only place where these boats are considered a factor is off the southeastern coast of Florida. The area of concern is covered by zones 075 and 076 on the map of figure IV-3. The counties of Palm Beach, Broward, and Dade are included in these two zones. These zones were used by an Office of Boating Safety study in their publication Recreational Boating in the Continental United States in 1973 and 1976.[1]

The number of boats for these two areas was not given; therefore, a number of assumptions had to be made. The Office of Boating Safety publishes annually the number of officially registered boats in the United States and in each individual state.[2] In addition, they estimate a total number of boats for the U.S. Therefore, the percentage of total boats to official boats in the United States was applied to the official number of boats in Florida to estimate the total Florida boat population. These are all 1976 figures. The results are as follows:

$$\frac{12{,}750{,}000 \text{ total U.S. boats}}{7{,}671{,}213 \text{ official U.S. boats}} = 1.662$$

436,348 official Florida boats x 1.662 = 725,236 total Florida boats

Since there are 2,179,105 households in Florida, the average number of boats per household is 0.333. The number of households in zones 075 and 076 is 1,058,075. It was assumed that the Florida average of 0.333 boats per household applies to these zones. This results in an estimate of 352,142 boats in zones 075 and 076.

The Office of Boating Safety estimated that 11.2 percent of all U.S. boats were not operational in 1976. Subtracting this percentage of boats from the number in the area of concern leaves 312,702 operational boats. The average U.S. boat was used 199.2 hours during the year with each outing an average of 5.3 hours. Applying these numbers to the boats in this area results in 32,200 boat trips per day.

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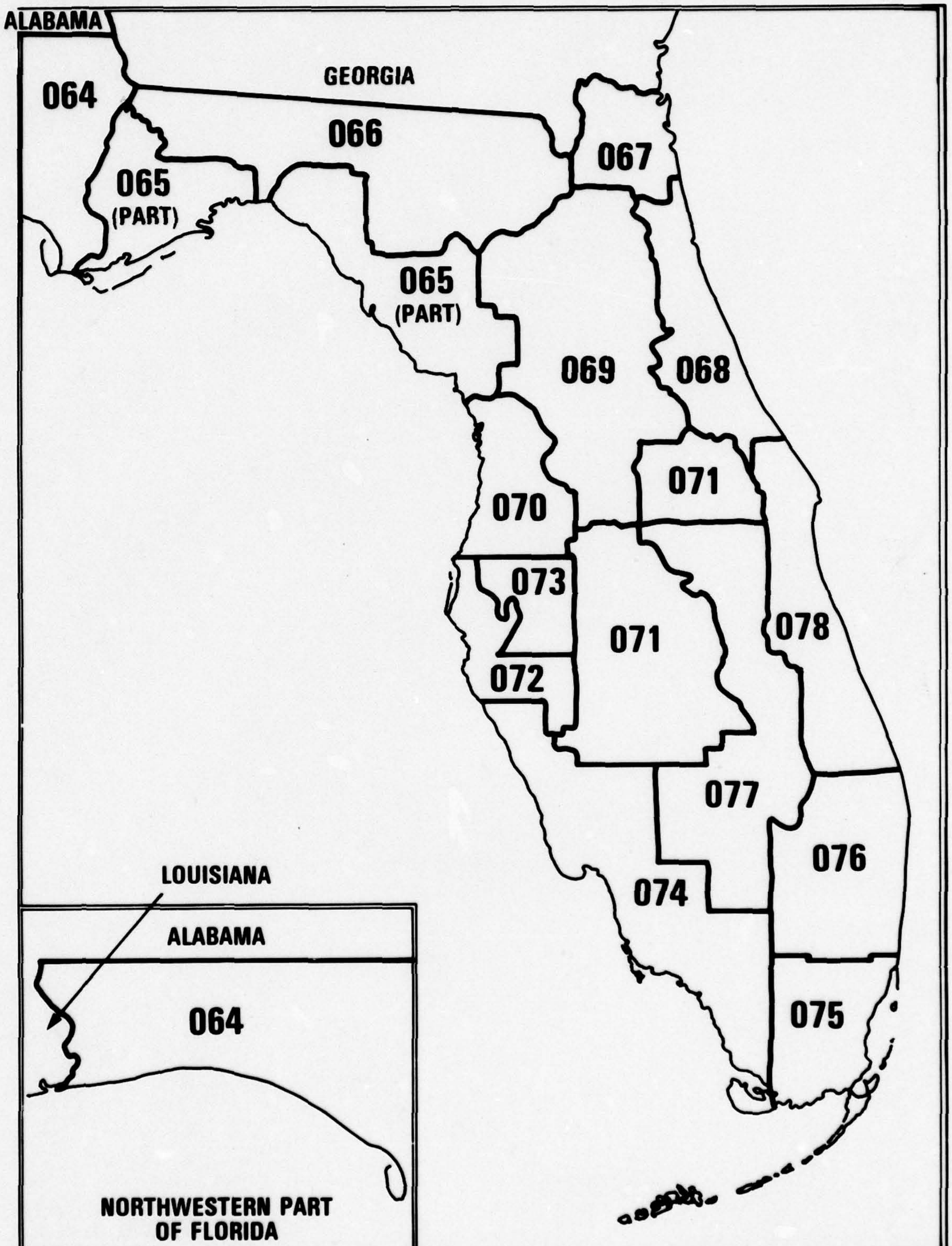
1. U.S. Coast Guard. Office of Boating Safety, Recreational Boating in the Continental United States in 1975 and 1976: The Nationwide Boating Survey, U.S. Department of Transportation, 1978.
2. U.S. Coast Guard, Office of Boating Safety, Boating Statistics, 1976, U.S. Department of Transportation, 1977.



SOURCE: U.S. Department of Transportation, USCG, Office of Boating Safety, *Recreational Boating in the Continental United States in 1973 and 1976,* (Washington, D.C., 1978).

FIGURE IV-3. FLORIDA ZONES FOR RECREATIONAL BOATING STUDY

There is no question that this is a large number of boats. However, it must be remembered that not all of these boats will be out in the ocean; many will be inland. Also, relatively few will be further than 3 miles offshore where the tankers will be traveling. While these boats do constitute a hazard to the tankers, the hazard is substantially less than this estimate of boat trips indicate.

2. Historical Tanker Exposure Data

In order to develop tanker oil spill rates from historical casualty data, a measure of the exposure over which the casualties occurred is required. The exposure measures used in the analysis of section V are tanker-days in operation and port calls over a given period.

The tanker population used in the analysis is comprised of tankers over 20,000 DWT. This value was selected as the cutoff because (1) the tanker population expected to utilize the deepwater ports are the larger tankers, and (2) analysis of tanker spill data indicates a significant difference between tankers less than 20,000 DWT and those greater, with no significant cutoff evident for values above 20,000 (this analysis is presented in section V).

Tanker casualty data are available from the Tanker Casualty File for the years 1969-1973. Exposure data were computed for world-wide tankers for these years. Data on population of world-wide tankers were extracted from "A Statistical Analysis of the World's Merchant Fleet."[1] Data are available (beginning from 1968) for alternate years up to 1976. Interpolation of data was necessary for the intermediate years, i.e., 1969, 1971, 1973. Table IV-6 presents the number of tankers with 20,000 DWT as a cutoff for the period 1969-1973.

TABLE IV-6. WORLD-WIDE TANKER POPULATION (≥1000GT)

Year	<20,000 DWT	>20,000 DWT	Total
1969	1,985	2,081	4,066
1970	1,997	2,235	4,232
1971	2,053	2,384	4,437
1972	2,108	2,473	4,581
1973	2,163	2,694	4,857
Total	10,306	11,867	22,173

1. Maritime Administration, A Statistical Analysis of the World's Merchant Fleet, U.S. Department of Commerce, December 1977.

Thus, exposure for 11,867 tankers ($\geq$20,000 DWT) was computed based on the following assumptions from LOOP and SEADOCK environmental impact statements.

- On the average, a tanker covers 6,100 miles one way per year. Therefore, for a round trip (two ways), a tanker will cover 12,200 miles/year.
- Each tanker makes 8.97 voyages per year.[1]
- The average speed is 15 knots.
- Each tanker spends 4 days at pier per round trip.

Based on the above assumptions, the total tanker days for 11,867 tankers is calculated as follows:

- At 12,200 miles/tanker/round trip for 8.97 voyages/year, the total tanker miles are:

  8.97 x 12,200 = 109,434 miles/year/tanker.
- There were 11,867 tankers ($\geq$20,000 DWT) from 1969-1973.

Therefore, the total tanker-miles are: 11,867 x 109,434 = 1,298,653,278.

- At 15 knots and 24 hours a day, 15 x 24 = 360 miles will be covered by a tanker per day. Thus, total tankers-days at sea are 3,607,370.
- At 4 days/voyage/year/tanker at pier, and at 8.97 voyages/year, for 11,867 tankers:

  11,867 x 8.97 x 4 = 425,788 tanker days at pier.
- Therefore, the total tanker/days for 11,867 tankers from 1969-1973 = 3,607,370 + 425,788 = 4,033,158 tanker-days.
- At two port calls/voyage and 8.97 voyages/year, the total port calls over the period are: 11,867 x 8.97 x 2 = 212,894 port calls.

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1. This number is derived on p. B-32, Volume 3 of the LOOP EIS.

3. Deepwater Port Traffic Projections

The traffic projections for the deepwater ports were derived from information in the LOOP and SEADOCK Environmental Impact Statements.[1,2] The number of port calls for two levels of throughput are given in table IV-7:

TABLE IV-7. PORT CALLS FOR DIFFERENT LEVELS OF THROUGHPUT

Port	Throughput Million Barrels Per Day, (MMBD)	Port Calls Per Year
LOOP	2.0	501
	3.0	675
SEADOCK	2.5	569

In addition, the EIS has estimated the number of loaded and ballast tankers by the three Gulf routes. These numbers are based on 501 and 675 port calls for LOOP. (See table IV-8.) The port calls for 2.5 MMBD for SEADOCK in table IV-7 were apparently extrapolated to obtain the figures for 2 and 4 MMBD in table IV-8.

Table IV-9 presents the estimated volume throughput, port calls, and transits for each route within the Gulf to and from LOOP (loaded and ballasted tankers, respectively). In order to determine the figures in table IV-9, the following assumptions were made:

- The volume throughput at each 5-year interval between 1980-2010 will be as given in the LOOP EIS.
- The total number of port calls is based on the relationship between volume throughput and port calls given in table IV-7. The relationship of 2.0 MMBD to 501 port calls is used in years when volume throughput is estimated to be less than 2.5 MMBD; the relationship 3.0 MMBD to 675 port calls is used when volume throughput is expected to be greater than or equal to 2.5 MMBD.

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1. U.S. Coast Guard, Final Environmental Impact/4(f) Statement LOOP Deepwater Port License Application (Department of Transportation, 1976).
2. U.S. Coast Guard, Final Environmental Impact Statement SEADOCK Deepwater Port License Application (Department of Transportation, 1976).

Table IV-8. DWP Traffic By Routes

LOOP

	Annual Number of Loaded Tankers				Annual Number of Ballast Tankers				Nautical Miles to LOOP
	2 MMBD*	Percent	3 MMBD	Percent	2 MMBD	Percent	3 MMBD	Percent	
Florida Straits (Fort Pierce)	15	3.0	23	3.4	15	3.0	23	3.4	852
Florida Straits (Old Bahama Channel)	22	4.4	33	4.9	173	34.5	259	38.4	622
Yucatan Channel	464	92.6	619	91.7	313	62.5	393	58.2	515
Total Port Calls	501	100.0	675	100.0	501	100.0	675	100.0	

SEADOCK

	Annual Number of Loaded Tankers				Annual Number of Ballast Tankers				Nautical Miles to SEADOCK
	2 MMBD*	Percent	4 MMBD	Percent	2 MMBD	Percent	4 MMBD	Percent	
Florida Straits (Fort Pierce)	7	1.9	15	2.1	7	1.9	15	2.1	1102
Florida Straits (Old Bahama Channel)	25	6.9	51	7.0	194	53.4	381	52.6	892
Yucatan Channel	331	91.2	659	90.9	162	44.6	329	45.4	704
Total Ports Calls	363	100.0	725	100.0	363	100.0	725	100.0	

*Million barrels per day.

78

Table IV-9. Estimated Volume Throughput and Port Calls for LOOP, 1980 - 2010

	1980	1985	1990	2000	2010
LOOP					
Throughput[1] (MMBD)	1.3	1.9	2.6	3.4	3.4
LOOP					
Port Calls	326	476	585	765	765
Transits by Loaded Tankers					
Florida Straits (Fort Pierce)	10	14	20	26	26
Florida Straits (Old Bahama Channel)	14	21	29	37	37
Yucatan Channel	302	441	536	702	702
Transits by Ballast Tankers					
Florida Straits (Fort Pierce)	10	14	20	26	26
Florida Straits (Old Bahama Channel)	112	164	224	294	294
Yucatan Channel	204	298	341	445	445

[1]LOOP EIS Estimates, Volume 1, pages 1 through 153.

- The number of loaded and ballast tankers for each route are calculated by applying the percentage of tankers along each route to the total number of port calls. These percentages are found in table IV-8. Once again, the percentage for 2.0 MMBD were used when expected volume throughput is less than 2.5 MMBD; and percentages for 3.0 MMBD are used when throughput is greater than or equal to 2.5 MMBD.

The same type of procedure was used in developing table IV-10 for SEADOCK. The assumptions used were:

- The volume throughput will be as given in the SEADOCK EIS.
- The total number of port calls is based on an expected 1.56 port calls per day when volume throughput is 2.5 MMBD. This means when volume throughput is 2.5 MMBD, the number of annual port calls is 569. Therefore, the relationship of 2.5 MMBD/569 port calls is used to calculate port calls for future years.
- The number of loaded and ballast tankers for each route are calculated by applying the percentage of tankers along each route to the total number of port calls. These percentages are found in table IV-8. This table was developed from information in the SEADOCK EIS which assumes 363 port calls per year at 2.0 MMBD and 725 annual port calls at 4.0 MMBD. The percentage for 2.0 MMBD are used when expected volume throughput is less than 3.0 MMBD; and percentages for 4.0 MMBD are used when throughput is greater than an equal to 4.0 MMBD.

The estimated tanker-miles and port calls for LOOP and SEADOCK for each 5-year period from 1980-2009 were determined by linear interpolation of the data shown in the previous tables. The results are shown in tables IV-11 through IV-14.

Tanker-days at sea and unloading were estimated by assuming an average speed of 15 knots and 1 day in the deepwater port. Table IV-15 presents these results for LOOP and SEADOCK.

Table IV-10. Estimated Volume Throughput and Port Calls for SEADOCK 1980 - 2010

	1980	1990	2000	2010
SEADOCK				
Throughput[1]	2.5	4.4	4.4	4.8
SEADOCK				
Port Calls	569	1001	1001	1092
Transits by Loaded Tankers				
Florida Straits (Fort Pierce)	11	21	21	23
Florida Straits (Old Bahama Channel)	39	70	70	77
Yucatan Channel	519	910	910	992
Transits by Ballast Tankers				
Florida Straits (Fort Pierce)	11	21	21	23
Florida Straits (Old Bahama Channel)	304	526	526	574
Yucatan Channel	254	454	454	495

[1] Estimated in SEADOCK EIS, Volume 1, pages 1 through 130.

Table IV-11. Estimated LOOP Tanker Miles, 1980-2010

	1980	1985	1990	2000	2010
Loaded Tanker Miles					
Florida Straits (Fort Pierce)	8,525	11,935	17,050	22,165	22,165
Florida Straits (Old Bahama Channel)	8,715	13,072	18,052	23,032	23,032
Yucatan Channel	155,681	227,335	276,308	361,881	361,881
Total	172,921	251,343	311,410	407,078	407,078
Ballast Tanker Miles					
Florida Straits (Fort Pierce)	8,525	11,935	17,050	22,165	22,165
Florida Straits (Old Bahama Channel)	69,720	102,090	139,440	183,015	183,015
Yucatan Channel	105,162	153,619	175,785	229,397	229,397
Total	183,407	267,644	332,275	434,275	434,577
Grand Total	356,328	519,987	643,686	841,656	841,656

Table IV-12. Estimated SEADOCK Tanker Miles, 1980 - 2010

	1980	1990	2000	2010
Loaded Tanker Miles				
Florida Straits (Fort Pierce)	12,116	23,131	23,131	25,334
Florida Straits (Old Bahama Channel)	33,988	61,005	61,005	67,105
Yucatan Channel	365,376	640,640	640,640	698,368
Total	411,481	724,776	724,776	790,808
Ballast Tanker Miles				
Florida Straits (Fort Pierce)	12,116	23,131	23,131	25,334
Florida Straits (Old Bahama Channel)	264,936	458,409	458,409	500,241
Yucatan Channel	178,816	319,616	319,616	348,480
Total	455,868	801,156	801,156	874,055
Grand Total	867,349	1,525,933	1,525,933	1,664,863

Table IV-13. Tanker Miles for LOOP and SEADOCK, 1980 - 2009

Time Frame	LOOP	SEADOCK
1980 -- 1984	2,108,958	4,995,329
1985 -- 1989	2,847,333	6,641,789
1990 -- 1004	3,416,400	7,629,665
1995 -- 1999	3,911,325	7,629,665
2000 -- 2004	4,208,280	7,768,595
2005 -- 2009	4,208,280	8,115,920
Total: 1980 -- 2009	40,700,576	42,780,963

TABLE IV-14. PORT CALLS FOR LOOP & SEADOCK, 1980 - 2009

TIME FRAME	LOOP	SEADOCK
1980-1984	1,930	3,277
1985-1989	2,598	4,357
1990-1994	3,105	5,005
1995-1999	3,555	5,005
2000-2004	3,825	5,095
2005-2009	3,825	5,325
TOTAL: 1980-2009	18,838	28,064

Table IV-15. Tanker-Days for LOOP and SEADOCK, 1980 - 2009

Time Frame	LOOP	SEADOCK
1980 -- 1984	7,788	17,153
1985 -- 1989	10,507	22,806
1990 -- 1994	12,595	26,199
1995 -- 1999	14,420	26,199
2000 -- 2004	15,515	27,674
2005 -- 2009	15,515	27,869
Total: 1980 -- 2009	76,340	146,900

4. Offshore Lightering

In addition to the foregoing vessel traffic, there is a large amount of offshore lightering of oil from VLCCs to smaller vessels in the Gulf of Mexico as shown in table IV-16. The information from table IV-16 is plotted on the chart in figure IV-4.

C. Analysis of Casualty and Exposure Data

In an attempt to determine both causal and predictive reasons for vessel casualties, vessel spills, and volume spilled, a number of relationships were explored using regression analysis. The independent variables tested included port calls, volume throughput and vessel age. This section describes the results of these analyses.

1. Relationship Between Port Calls and Vessel Casualties

Using casualty data from VCRS, the total number of casualties as well as number by type of casualty were tested against port calls in seven major U.S. ports systems. The VCRS data used covered the calendar years 1969-1976 and included tanker casualties in which the tankers were greater than 5,000 gross tons. Only one tanker was counted in cases of multivessel casualties.

The number of tanker port calls was extracted from U.S. Waterborne Commerce data published by the U.S. Army Corps of Engineers. Tanker port calls included all inbound tankers greater than 18-foot draft. The seven major port systems and their definitions are:

- Chesapeake Bay including Baltimore Harbor, Hampton Roads, York River, and the Potomac River below Washington, D.C.
- Delaware Bay consisting of the Delaware River from Trenton, N.J. to the sea.
- Gulf Coast including the Sabine-Neches Waterway, Galveston Harbor, Freeport Harbor, Matagorda Shipping Channel, Corpus Christi Shipping Channel and Brazos Island Harbor.
- Los Angeles consisting of San Diego, Long Beach, Los Angeles, and El Segundo harbors.
- New York including New Haven, Bridgeport, and New York lower bay harbors.

Table IV-16. Offshore Lightering of Oil in the Gulf of Mexico

Company	Port of Cargo Distribution	Location Of Lightering	Volume
Chevron	Tuscaloosa, Alabama	29°-23'N 88°-32'W	4-6 ships per month 2 MMBM
Coastal States	Corpus Christi, TX	27°-25'N 97°-03'W	10-15 ships per month 6 MMBM
Conoco	Freeport, TX	28°-30'N 93°-54'W	10-12 ships per month 4 MMBM
Exxon	Baytown, TX	28°-20'N 94'-44'W	2 ships per month 2 MMBM
Gulf	Port Arthur, TX	28°-20'N 94'-10'W	4 ships per month 1 MMBM
Mobil	Beaumont, TX	28°-30'N 93°-30'W	12 ships per month 3-4 MMBM
Shell	Garyville, LA	28°-00'N 89°-30'W	16-20 ships per month 7 MMBM
Texaco	Port Arthur, TX	28°-30'N 93°-35'W	4 ships per month 1 MMBM

Note: Information obtained from the Port Security Branch, Eighth Coast Guard District, New Orleans, Louisiana.

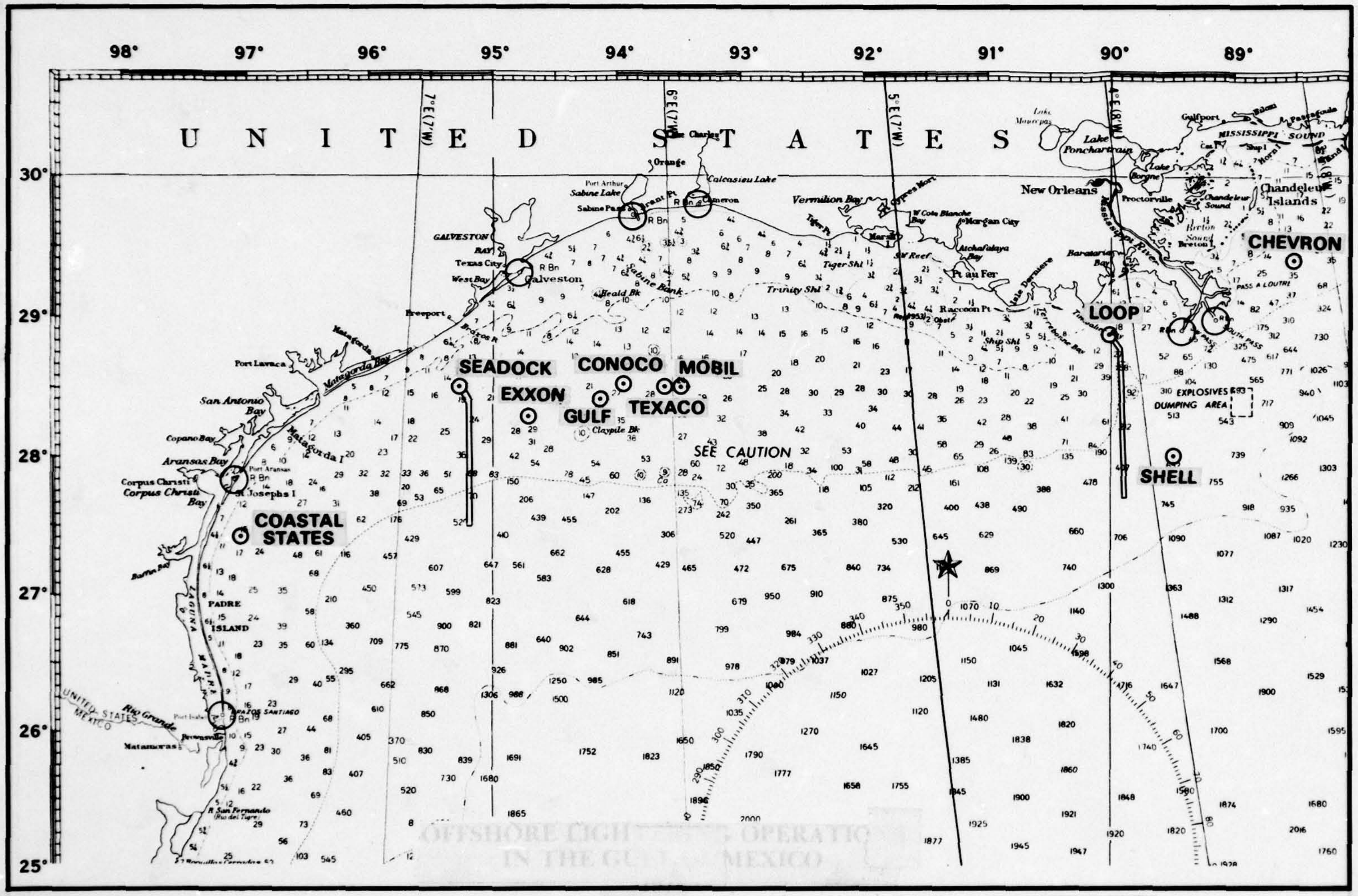

FIGURE IV-4. OFFSHORE LIGHTERING OPERATIONS IN THE GULF OF MEXICO 1978

- Puget Sound consisting of Port Angeles, Port Townsend Harbor, Tacoma Harbor, Seattle, Everett Harbor, Anacortes, Bellingham Bay and other Puget Sound ports (Cherry Point).
- San Francisco including San Francisco Harbor, Redwood City Harbor, Oakland Harbor, Richmond Harbor, Carquinez Strait and other San Francisco Bay ports.

Table IV-17 shows the number and type of casualties in each port system. The number of port calls for each port are shown in table IV-18.

Figures IV-5 through IV-12 show the results of these regressions. The slope, intercept, correlation (R) and goodness of fit (R^2) for each of these figures are summarized below:

All Types of Casualties:	Casualties = -7.192 + 0.0067 (port calls) $R = .97 \quad R^2 = .95$
Collisions:	Collisions = -4.226 + .0011 (port calls) $R = .98 \quad R^2 = .97$
Groundings:	Groundings = -.15.500 + .0034 (port calls) $R = .98 \quad R^2 = .95$
Rammings:	Rammings = 0.750 + 0.0017 (port calls) $R = .94 \quad R^2 = .88$
Impact Casualties (collisions, rammings and groundings):	Impact Casualties = -18.975 + .0063 (port calls) $R = .98 \quad R^2 = .96$
Explosions and Fires:	Explosions/Fires vs. Port Calls (no fit) $R = -.12 \quad R^2 = .01$
Structural Failures:	Structural Failures Vs. Port Calls (no fit) $R = .42 \quad R^2 = .18$
Non-impact Casualties (explosions, fires, structural failures, capsizings, founderings, floodings, and heavy weather):	Non-impact Casualties vs. Port Calls (no fit) $R = .42 \quad R^2 = .18$

Table IV-17. Tanker Casualties in Seven Major Port Systems

Type Casualty	Chesapeake Bay	Delaware Bay	Gulf Coast	Los Angeles	New York	Puget Sound	San Francisco
	Port System						
Collision	7	15	27	5	30	2	5
Ramming	17	30	58	8	41	10	23
Grounding	18	51	80	3	80	3	16
Total Impact	42	96	165	16	151	15	44
Structural Failure	9	17	17	13	7	6	10
Explosion/ Fire	4	6	3	1	3	5	3
Capsizing	0	0	1	0	1	0	0
Foundering	0	0	1	0	0	1	1
Flooding	0	0	1	0	0	1	1
Heavy Weather	1	0	0	0	0	1	0
Total Non-Impact	14	23	23	14	11	13	14
Other	2	4	10	0	0	0	1
Grand Total	58	123	198	30	162	28	59

Note: Includes only tankers greater than 5,000 Gross Tons

Source: U.S. Coast Guard's Vessel Casualty Reporting System, 1969-1976

Table IV-18 Tanker Port Calls in Seven Major Port Systems

Year	Port System						
	Chesapeake Bay	Delaware Bay	Gulf Coast	Los Angeles	New York	Puget Sound	San Francisco
1969	1,051	2,358	3,347	1,202	3,276	447	1,204
1970	1,205	2,428	3,155	1,206	3,472	417	1,205
1971	1,181	2,344	3,046	1,245	3,515	359	1,215
1972	1,201	2,222	3,184	1,182	3,618	507	1,160
1973	1,210	2,231	3,838	1,368	3,913	538	1,182
1974	1,166	2,062	4,122	1,341	3,452	488	1,102
1975	1,116	1,762	3,987	1,092	2,925	490	1,040
1976	1,076	1,818	4,569	1,085	3,048	557	1,190
Total	9,206	17,225	29,238	9,721	27,219	3,803	9,298

Note: For tankers with Drafts Greater Than 18 Feet.

Source: U.S. Army Corps of Engineers, "Waterborne Commerce of the United States," 1969-1976.

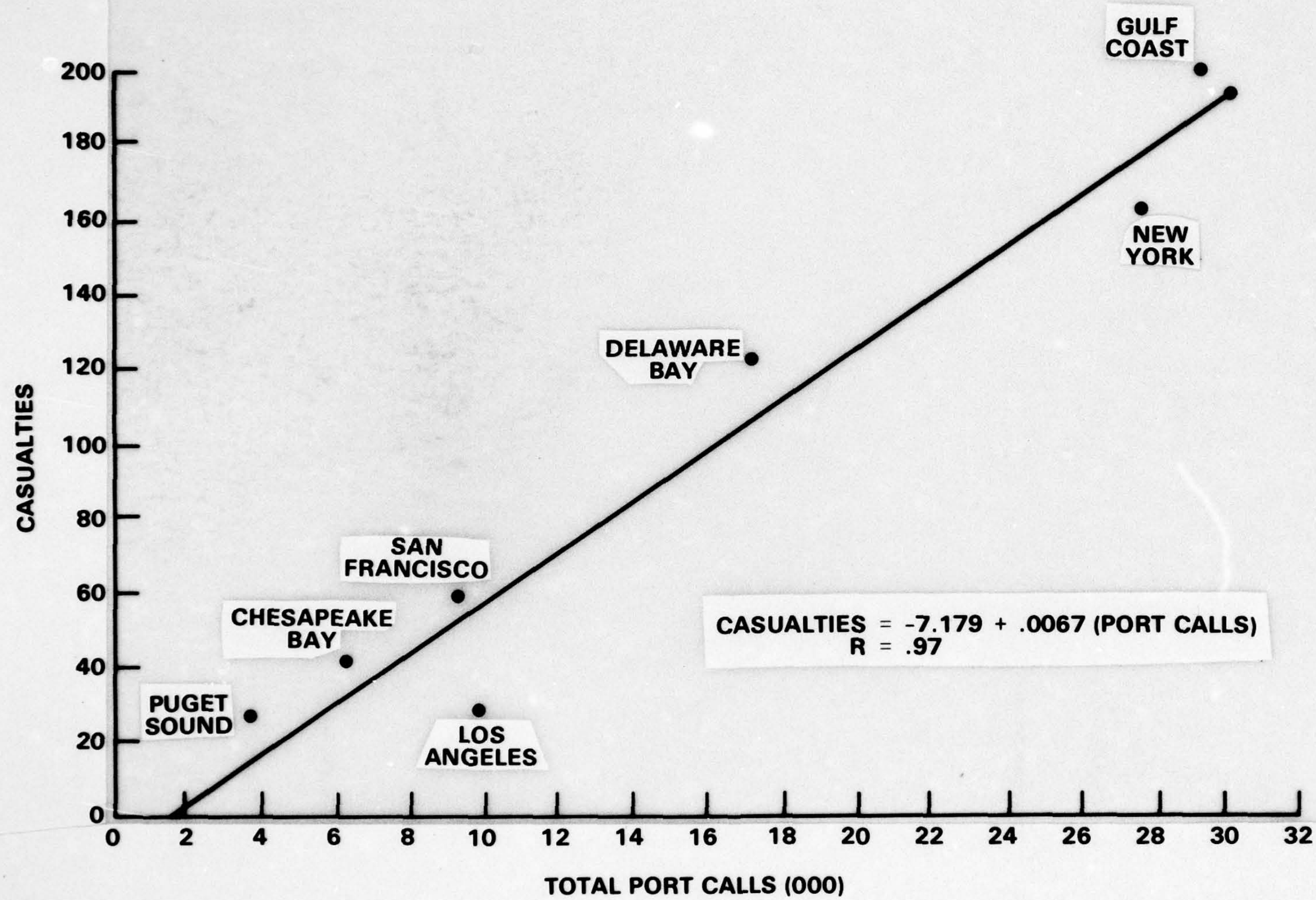

FIGURE IV-5. TOTAL TANKER (> 5,000 G.T.) CASUALTIES VS. TOTAL PORT CALLS IN SEVEN MAJOR PORT SYSTEMS 1969-1976

93

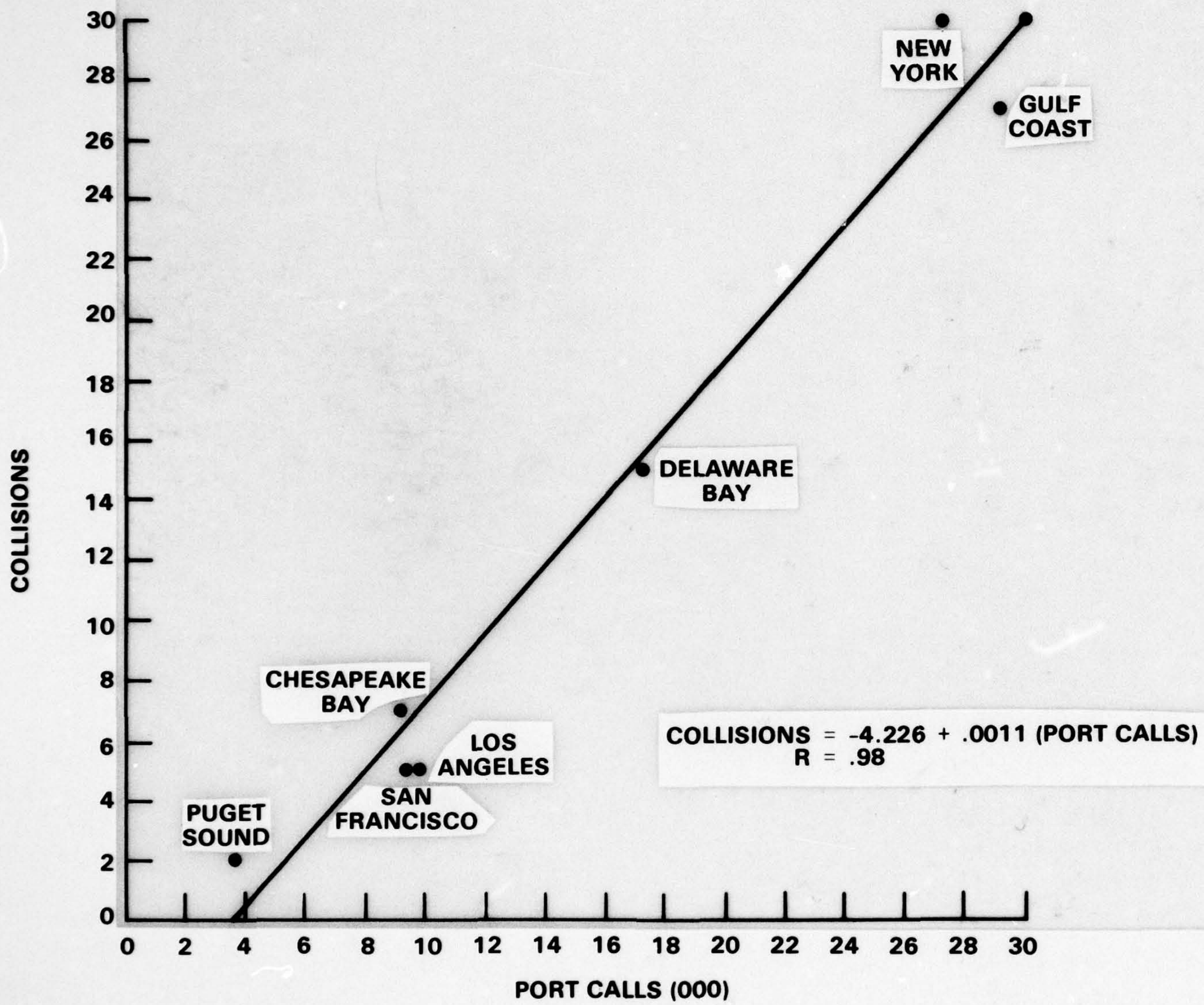

FIGURE IV-6. TANKER (> 5,000 GT) COLLISIONS VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1969-1976

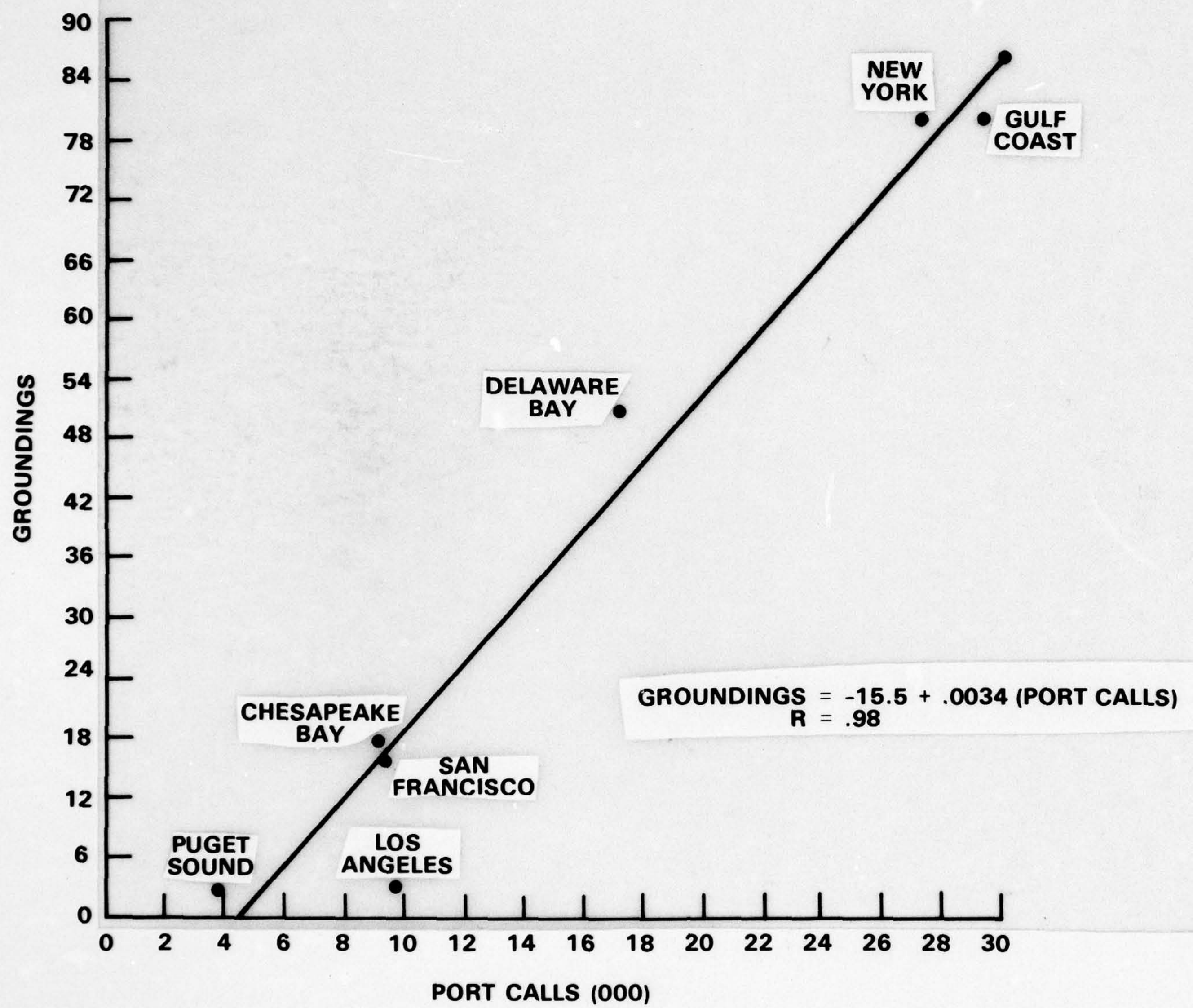

FIGURE IV-7. TANKER (> 5,000 GT) GROUNDINGS VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1969-1976

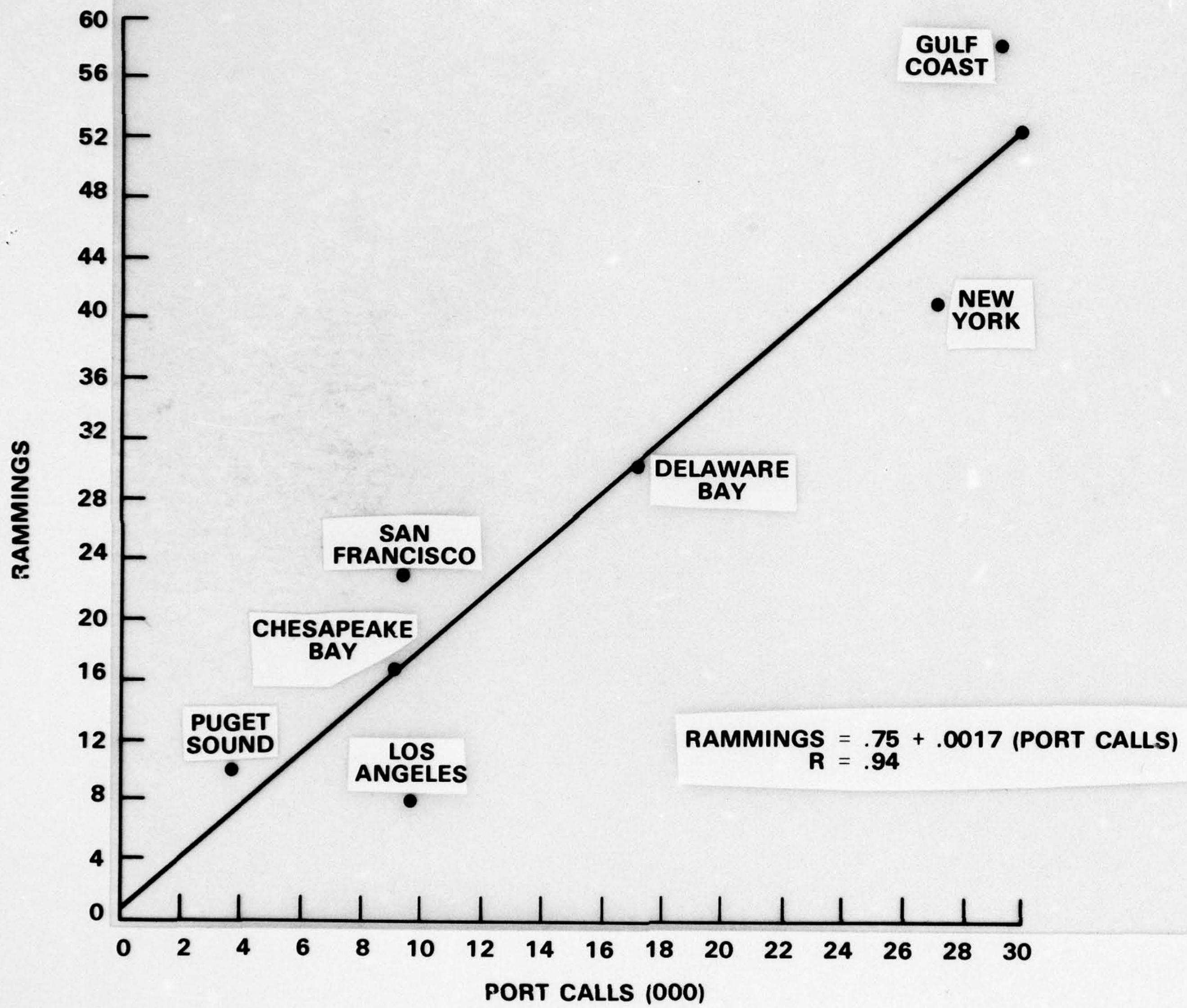

FIGURE IV-8. TANKER (>5,000 GT) RAMMINGS VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1969-1976

96

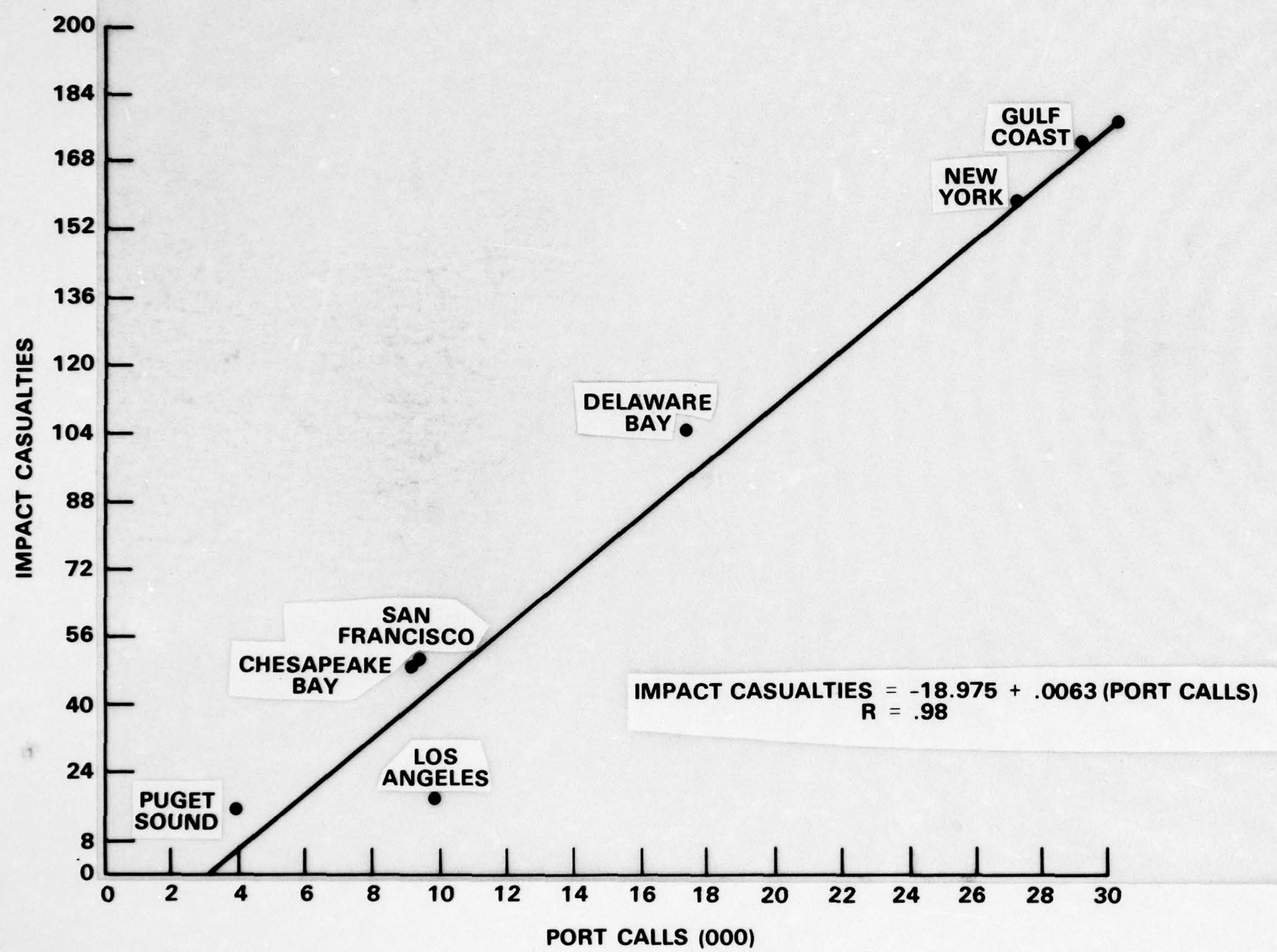

FIGURE IV-9. TANKER (>5,000 GT) IMPACT CASUALTIES VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1969-1976

97

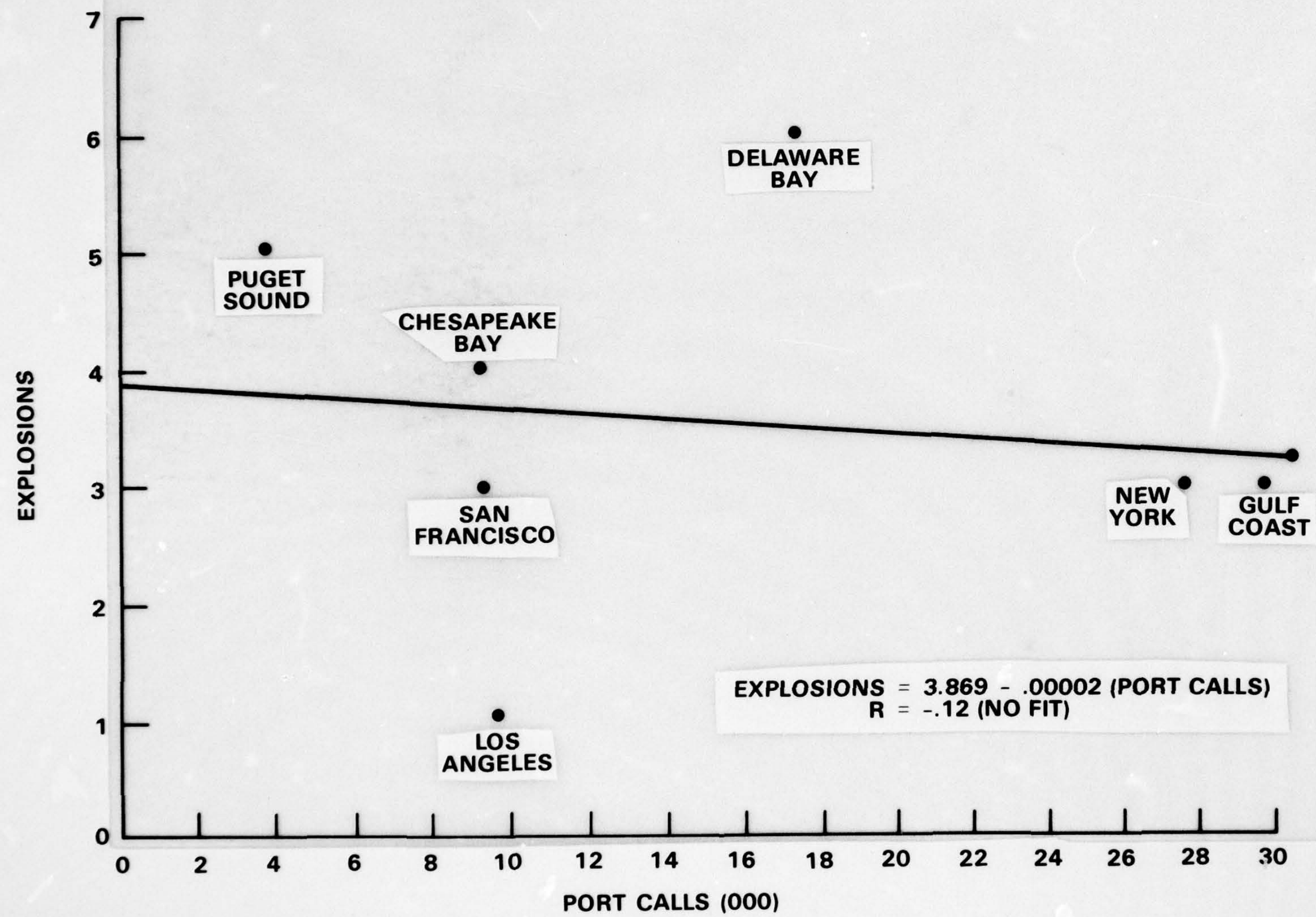

FIGURE IV-10. TANKER (>5,000 GT) EXPLOSIONS VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1969-1976

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DEEPWATER PORTS APPROACH/EXIT HAZARD AND RISK ASSESSMENT.(U)

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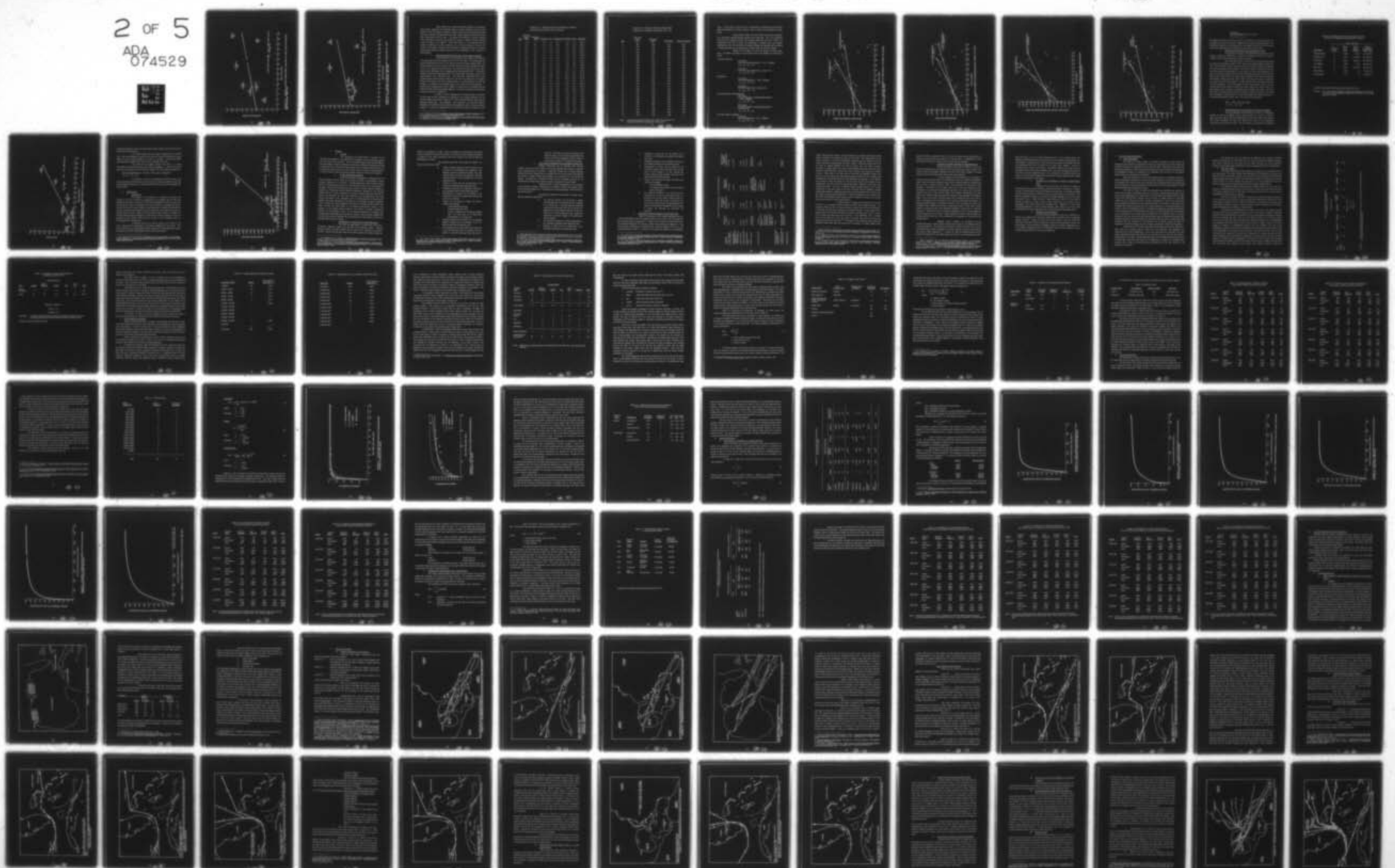

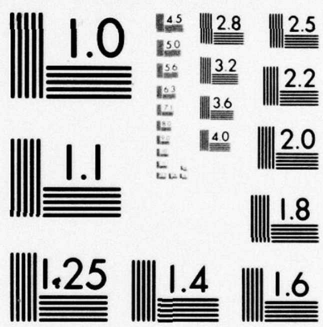

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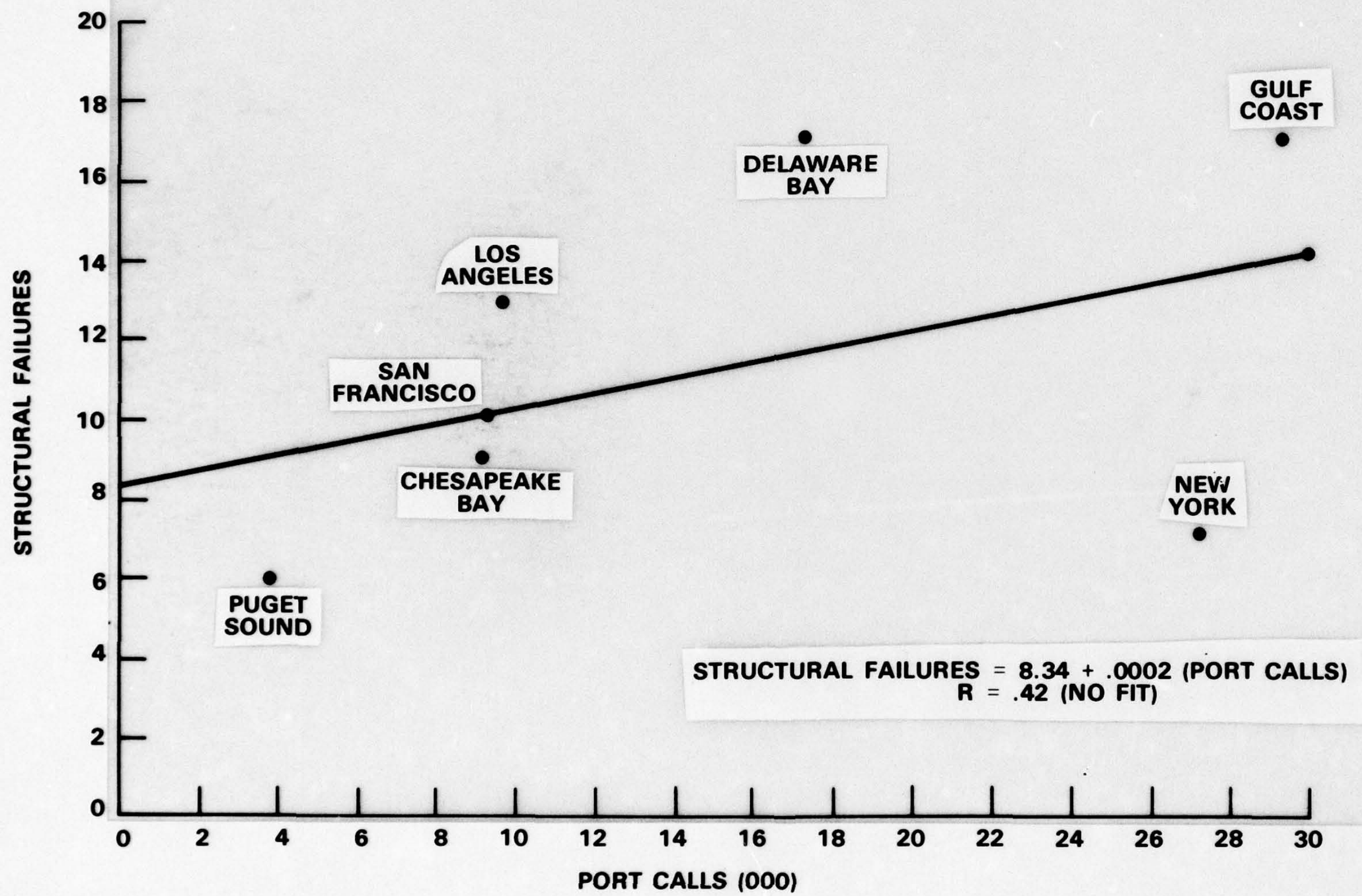

FIGURE IV-11. TANKER (> 5,000 GT) STRUCTURAL FAILURES VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1969-1976

99

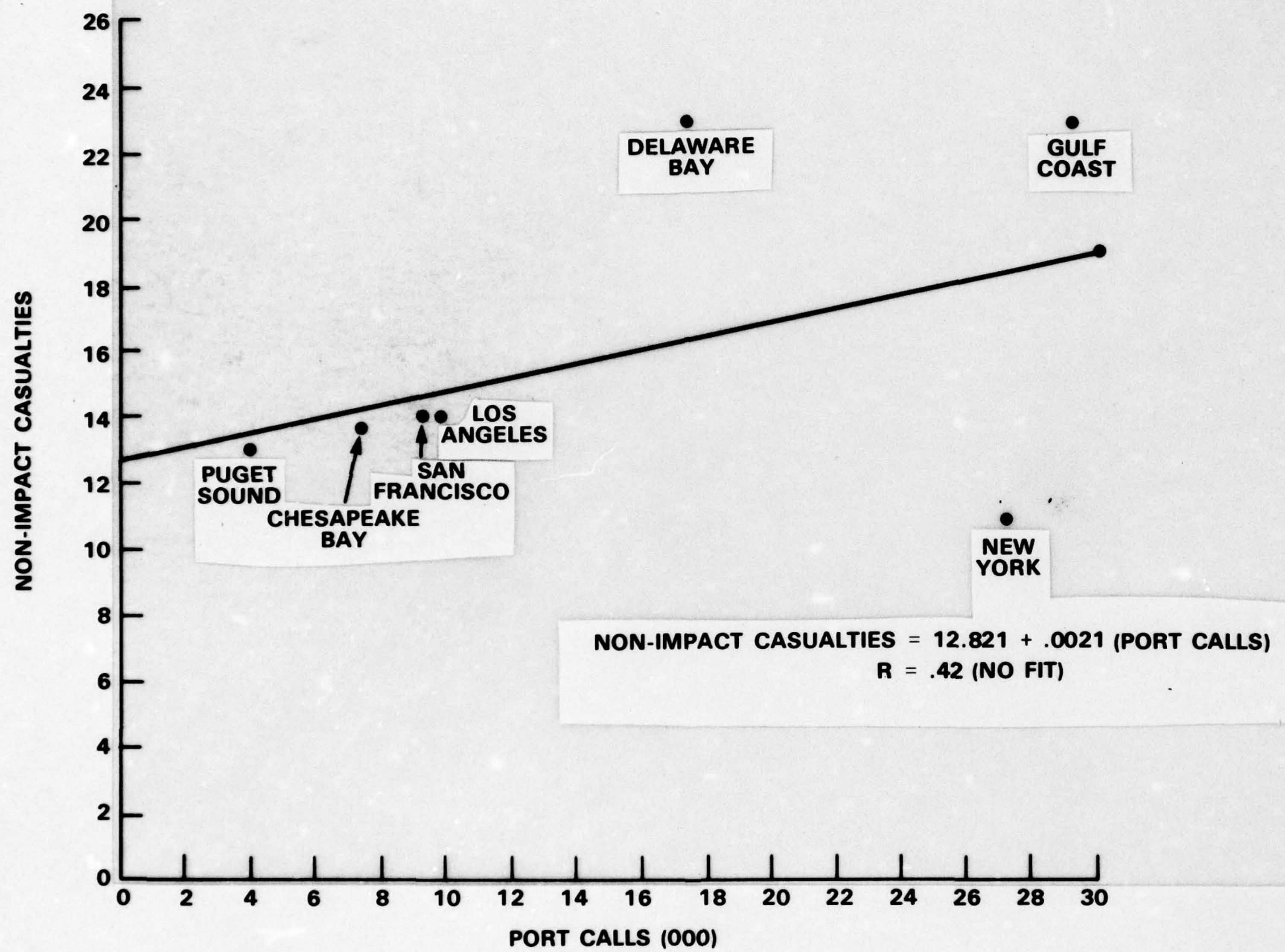

FIGURE IV-12. TANKER (>5,000 GT) NON-IMPACT CASUALTIES VS. PORT CALLS IN 7 MAJOR PORT SYSTEMS 1967-1976

101

100

These results show strong relationships between all casualties, total impact casualties and individual types of impact casualties and port calls. However, total non-impact casualties, explosions and fires, and structural failures show only a random relationship with port calls. These statistical analyses show what logic would expect them to show -- the greater the exposure to areas of shallow water, obstacles, and traffic the greater the chance a vessel will strike another vessel, an object, or the bottom. On the other hand, it is not expected that the amount of exposure to traffic, obstacles, etc., will have anything to do with the number of non-impact casualties since explosions, breakdowns, and other non-impact casualties generally are caused by factors that are independent of the presence of these hazards.

2. Relationship Between Vessel Age and Non-impact Casualties

It has been shown[1] that structural failure casualty rates increase with vessel age based upon analysis of the 1971-72 TCF data. This relationship was further analyzed using 5 years of TCF data and other non-impact casualty types. The Tanker Casualty File gives the year in which the ship was built, allowing the age at the time of a casualty to be determined. The casualty data used were for all vessels greater than 1,000 gross tons for casualties occuring during 1969-1973. "A Statistical Analysis of the World's Merchant Fleet"[2] lists world tanker population by age for all vessels greater than 1,000 gross tons. This document is published only in even numbered years so that values for 1969, 1971, and 1973 were taken to be the midpoint between the values for the even numbered years, i.e., 1969 population for each age category was assumed to be halfway between the 1968 and 1970 populations. A cutoff point of vessels greater than or equal to 26 years had to be establishd because ships built before 1941 were grouped together. The annual casualties and populations by age are presented in table IV-19.

In order to run the regressions, the average number of casualties for each age was first normalized by dividing by the average population for the respective ages as presented in table IV-20. This normalized casualty value was then regressed against age. The regressions were performed for structural failures, breakdowns, combined structural failures and breakdowns, and for total non-impact casualties. In each case, regressions were performed for ages 0-20 years and 0-26

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1. J. J. Henry Co., Inc., An Analysis of Oil Outflows Due to Tanker Accidents, 1971-1972, prepared for the U.S. Coast Guard, November 1973.
2. Maritime Administration, A Statistical Analysis of the World's Merchant Fleet, U.S. Department of Commerce, December 1976.

TABLE IV-19. AVERAGE ANNUAL NON-IMPACT TANKER CASUALTIES AND POPULATION, 1969-1973

Age	Structural Failure (STF)	Breakdown (BKD)	Explosion	Fire	Capsizing	STF & BKD	Total	Population
0	1.8	1.4	0.8	1.4	0.0	3.2	5.4	232.0
1	5.0	3.0	1.2	2.4	0.0	8.0	11.6	251.6
2	3.0	2.2	1.2	2.6	0.0	5.2	9.0	218.6
3	4.4	1.8	1.0	1.6	0.0	6.2	8.8	222.4
4	4.2	2.2	1.6	2.2	0.0	6.4	10.2	200.4
5	4.2	2.2	1.2	1.6	0.2	6.4	9.4	192.8
6	3.8	1.2	0.2	1.8	0.2	5.0	7.2	191.0
7	3.6	2.8	1.4	1.6	0.0	6.4	9.4	176.4
8	3.6	2.6	1.0	1.4	0.0	6.2	8.6	187.2
9	4.0	2.0	0.8	2.4	0.2	6.0	9.4	172.2
10	3.4	2.2	0.4	1.6	0.0	5.6	7.6	193.0
11	4.4	5.4	0.2	1.4	0.0	9.8	11.4	199.8
12	8.4	3.4	1.4	2.0	0.0	11.8	15.2	211.2
13	5.6	4.4	1.4	2.0	0.0	10.0	13.4	210.4
14	4.8	5.4	0.8	2.2	0.0	10.2	13.2	197.6
15	6.6	5.4	0.6	3.4	0.2	12.0	16.2	191.0
16	7.4	5.6	1.2	3.0	0.0	13.0	17.2	182.4
17	6.0	3.0	0.8	2.4	0.0	9.0	12.2	157.6
18	5.2	4.8	0.8	1.0	0.0	10.0	11.8	144.0
19	3.6	3.0	0.4	1.8	0.0	6.6	8.8	115.0
20	4.0	2.0	0.6	0.6	0.0	6.0	7.2	87.6
21	2.0	0.8	0.0	0.4	0.0	2.8	3.2	66.0
22	1.4	1.2	0.6	0.0	0.0	2.6	3.2	44.0
23	0.6	0.2	0.2	0.0	0.0	0.8	1.0	38.6
24	1.0	0.8	0.2	0.4	0.0	1.8	2.4	24.8
25	0.4	1.4	0.2	0.2	0.0	1.8	2.2	54.2
26	0.2	1.2	0.0	0.2	0.0	1.4	1.6	39.2
27+	0.6	0.4	N/A	N/A	N/A	1.0	N/A	233.6

TABLE IV-20. AVERAGE ANNUAL NORMALIZED NON-IMPACT TANKER CASUALTIES, 1969 - 1973

Age	Structural Failure STF	Breakdown BKD	STF & BKD	Total Non-Impact
0	.008	.006	.014	.023
1	.020	.012	.032	.046
2	.014	.010	.024	.041
3	.020	.008	.028	.040
4	.021	.011	.032	.051
5	.022	.011	.033	.049
6	.020	.006	.026	.038
7	.020	.016	.036	.053
8	.019	.014	.033	.046
9	.023	.012	.035	.055
10	.018	.011	.029	.039
11	.022	.027	.049	.057
12	.040	.016	.056	.072
13	.027	.021	.048	.064
14	.024	.027	.052	.067
15	.035	.028	.063	.085
16	.041	.031	.071	.094
17	.038	.019	.057	.077
18	.036	.033	.069	.082
19	.031	.026	.057	.077
20	.046	.023	.068	.082
21	.030	.012	.042	.048
22	.032	.027	.059	.073
23	.016	.005	.021	.026
24	.040	.032	.073	.097
25	.007	.026	.033	.041
26	.005	.031	.036	.041
27+	.003	.002	.004	—

Note: Normalized casualties equals actual number of casualties in an age group divided by the population in that group.

years. It was found in each case that a strong positive relationship exists between age and casualties for 20 years; however, after 20 years the relationship no longer holds.

These analyses indicate that for the first 20 years the probability of a non-impact casualty becomes greater with vessel age. This is not surprising since for any mechanical system the reliability decreases with time. While it is unexpected that after 20 years the relationship no longer holds, one possible explanation is that after 20 years the vessels, although still operable and still adding to vessel population, are not operated to the same extent as the newer vessels.

Figures IV-13 through IV-16 show the graphs for these regressions. The slopes, intercepts, and correlations from these analyses are summarized below:

Structural Failures:

0-20 years:
structural failures/population = .012 + .001(age)

$R = .85 \quad R^2 = .72$

0-26 years:
structural failures/population vs. age (no fit)

$R = .30 \quad R^2 = .09$

Breakdowns:

0-20 years:
breakdowns/population = .006 + .001(age)

$R = .83 \quad R^2 = .70$

0-26 years:
breakdowns/population vs. age (no fit)

$R = .66 \quad R^2 = .429$

Structural Failures and Breakdowns:

0-20 years:
(structural failures + breakdowns)/population
= .019 + .002(age)

$R = .92 \quad R^2 = .84$

0-26 years:
(structural failures + breakdowns)/population
vs. age (no fit)

$R = .55 \quad R^2 = .30$

Total Non-impact Casualties:

0-20 years:
casualties/population = .032 + .003(age)

$R = .89 \quad R^2 = .79$

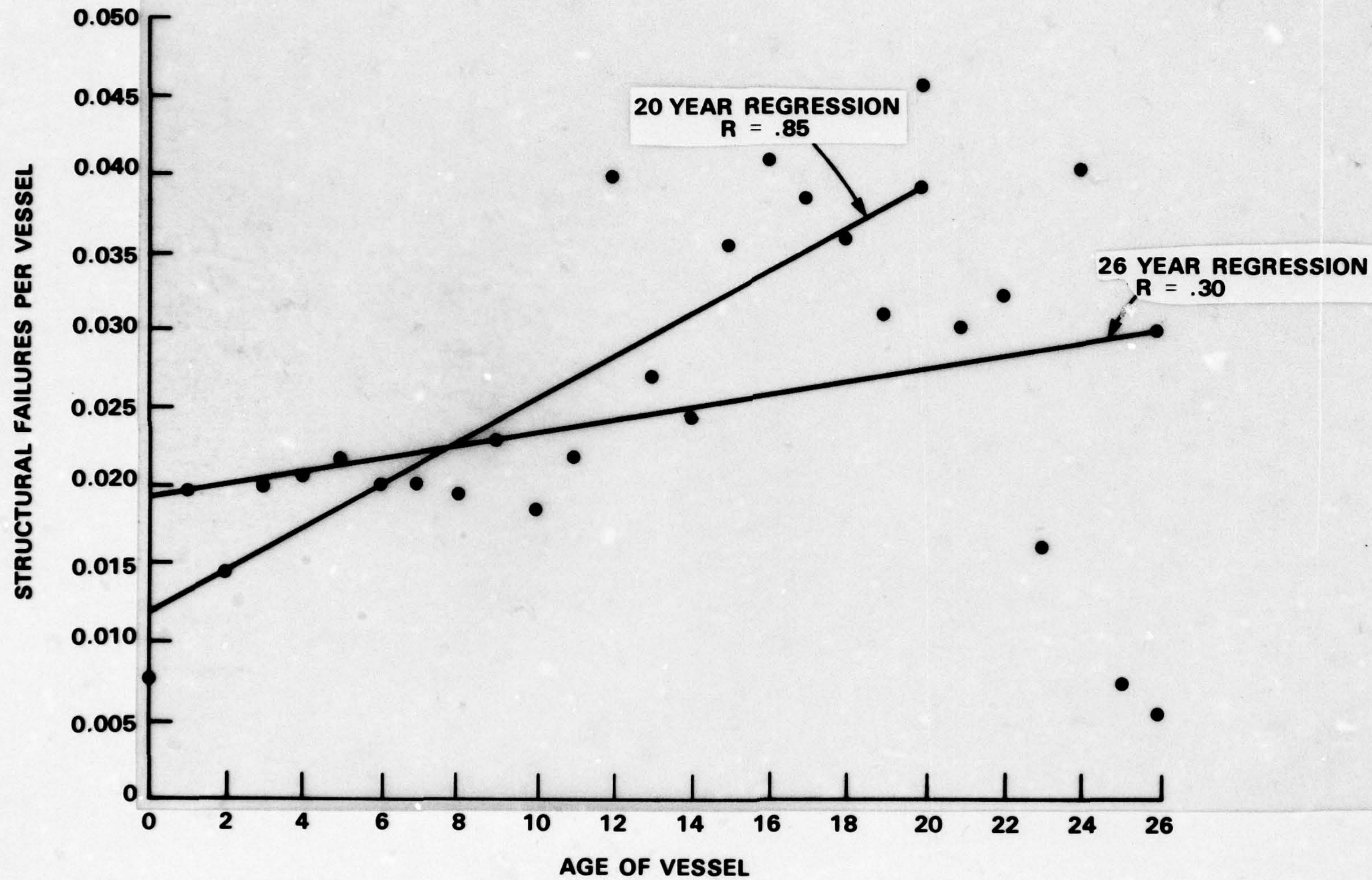

FIGURE IV-13. AVERAGE NUMBER OF STRUCTURAL FAILURES PER VESSEL VS. AGE OF VESSEL 1969-1973

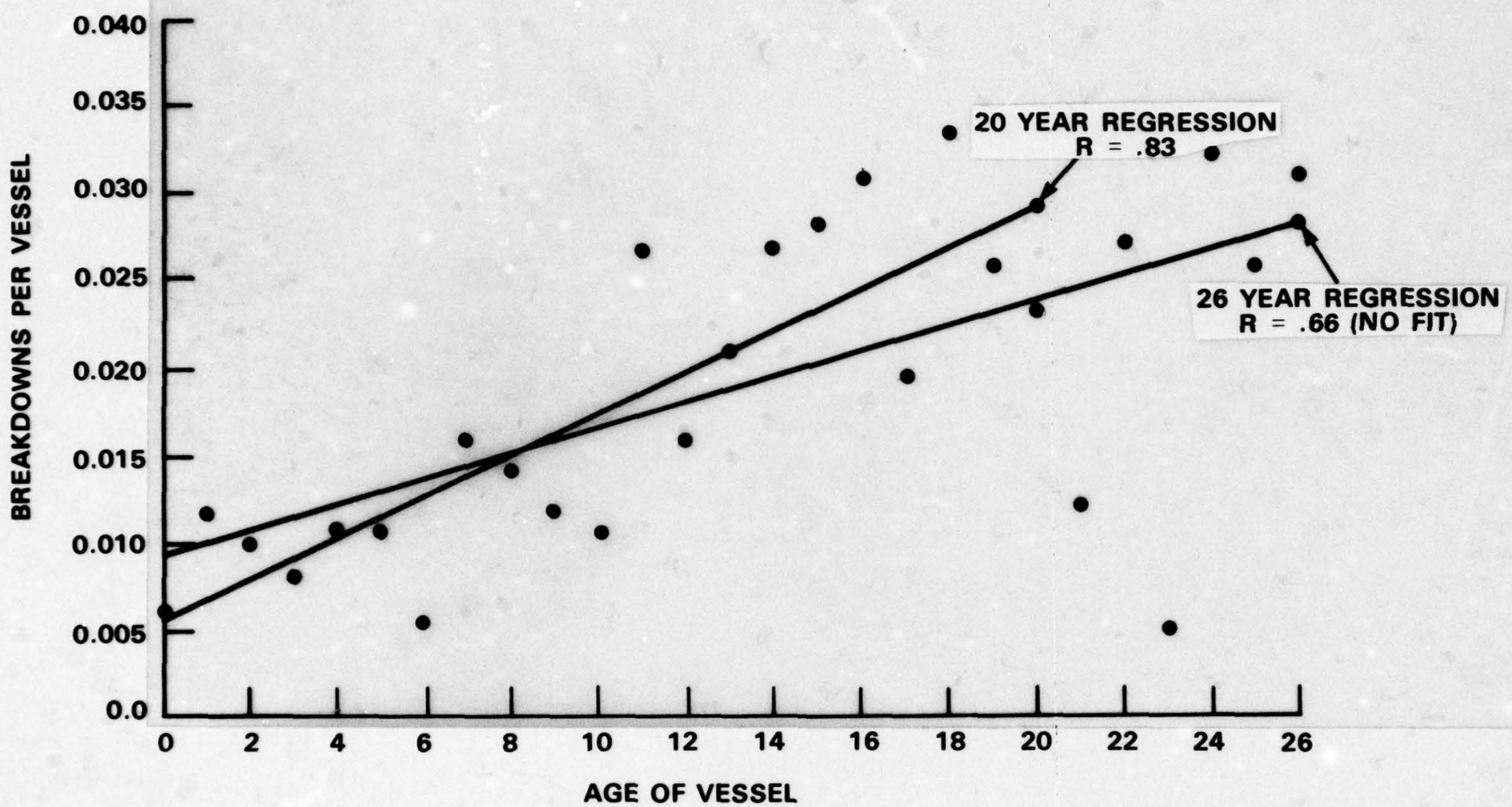

FIGURE IV-14. AVERAGE NUMBER OF BREAKDOWNS PER VESSEL VS. AGE OF VESSEL 1969-1973

(107) (106)

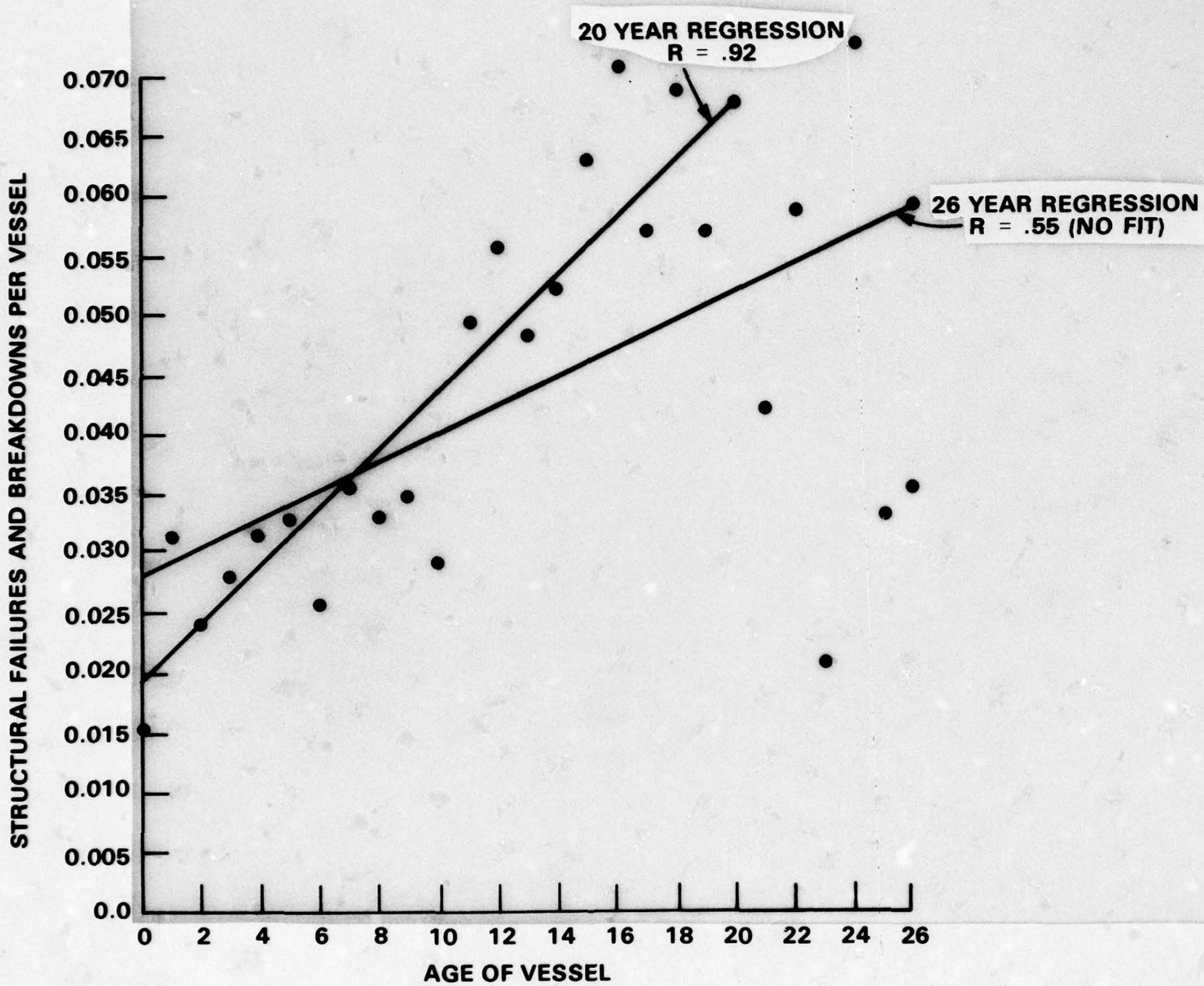

FIGURE IV-15. STRUCTURAL FAILURES AND BREAKDOWNS PER VESSEL VS. AGE OF VESSEL 1969-1973

107

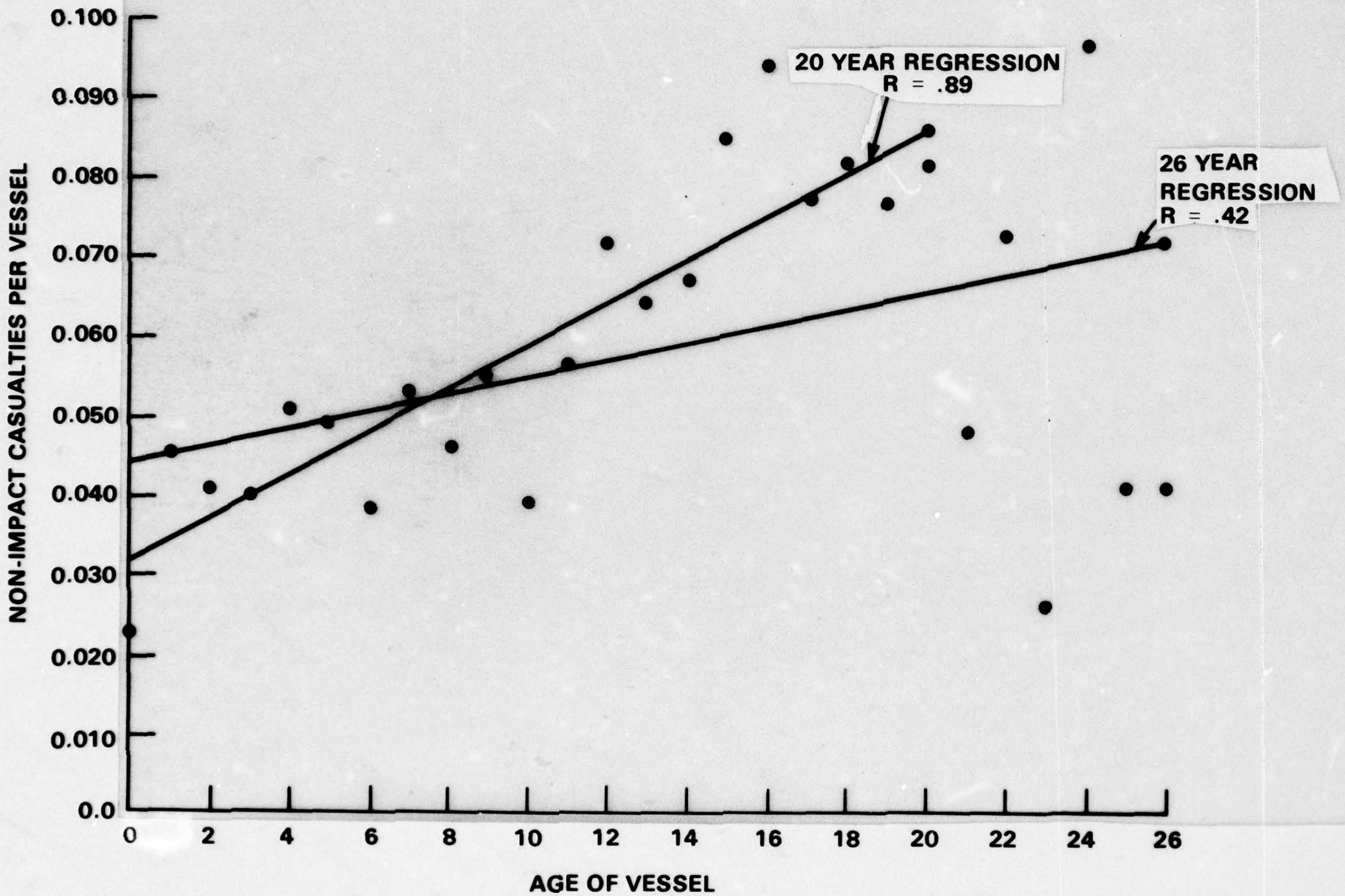

FIGURE IV-16. NON-IMPACT CASUALTIES PER VESSEL VS. AGE OF VESSEL
1969-1973

108

0-26 years:
casualties/population vs. age (no fit)
$R = .42 \quad R^2 = .18$

The highest correlation (.92) occurs for the combination of structural failures and breakdowns for the 20-year period. Adding other non-impact casualties degrades the correlation somewhat, but not significantly. One reason for this is that the structural failures and breakdowns tend to dominate the non-impact casualty rate.

3. Relationship Between Port Calls and Number of Spills

As important as finding a relationship between casualties and an exposure variable is determining a predictive relationship between an exposure variable and the number of spills as a result of a casualty.

Using the PIRS data for the seven major port systems described in section C, the number of spills in a port system was regressed against tanker port calls. The PIRS data was first reduced so that only oil carrying tankers having spills as a result of a casualty were included. The number of spills in a specific port system was determined by plotting spills on a map using the latitude and longitude of the spill. In this case, all tanker port calls were used rather than only those for tankers greater than 18-foot draft as in the analysis of casualties versus port calls because the spill data included all tanker spills. Table IV-21 shows the number of spills and port calls for the seven port systems. The spills include those resulting from all types of vessel casualties. It was not possible to break spill numbers down by type of casualty because the number is already very small. Figure IV-17 shows a plot of the spill number by port calls and the regression line through these points. As can be seen, there is a high correlation between number of spills and number of port calls. This relationship is expected since a strong relationship has already been shown to exist between casualties and port calls. The result of the regression is:

$$\text{Spills} = -2.744 + .0011 \text{ (port calls)}$$
$$R = .93 \quad R^2 = .86$$

4. Relationship Between Volume Spilled and Volume Throughput

The final regression was performed in search of a relationship between the volume throughput and the volume spilled as a result of a casualty. Again, the areas used to test this relationship were the seven major port systems. The volume throughput for these port systems was found in U.S. Waterborne Commerce for the years 1973-1976. The total volume was calculated by adding all

Table IV-21 Number of Spills, Volume Spilled, Port Calls, and Volume Throughput in Seven Major Port Systems

	1973 - 1976 Total			
Port System	Number of Spills	Tanker Port Calls	Volume Spilled (Gals.)	Volume Throughput 1/ (Short Tons)
Chesapeake Bay	7	13,048	2,676	117,305,497
Delaware Bay	8	9,764	1,007,080	257,040,292
Gulf Coast	16	18,877	322,487	167,593,535
Los Angeles	4	5,869	5,016	135,965,501
New York	27	23,243	1,421,518	340,232,251
Puget Sound	4	2,224	54	53,548,537
San Francisco	1	5,511	50	96,089,471

1/ Total Crude Oil and Petroleum Products Brought into Port.

Sources: U.S. Coast Guard's "Pollution Incident Reporting System," 1973-1976; U.S. Army Corps of Engineers, "Waterborne Commerce of the United States," 1973-1976.

110

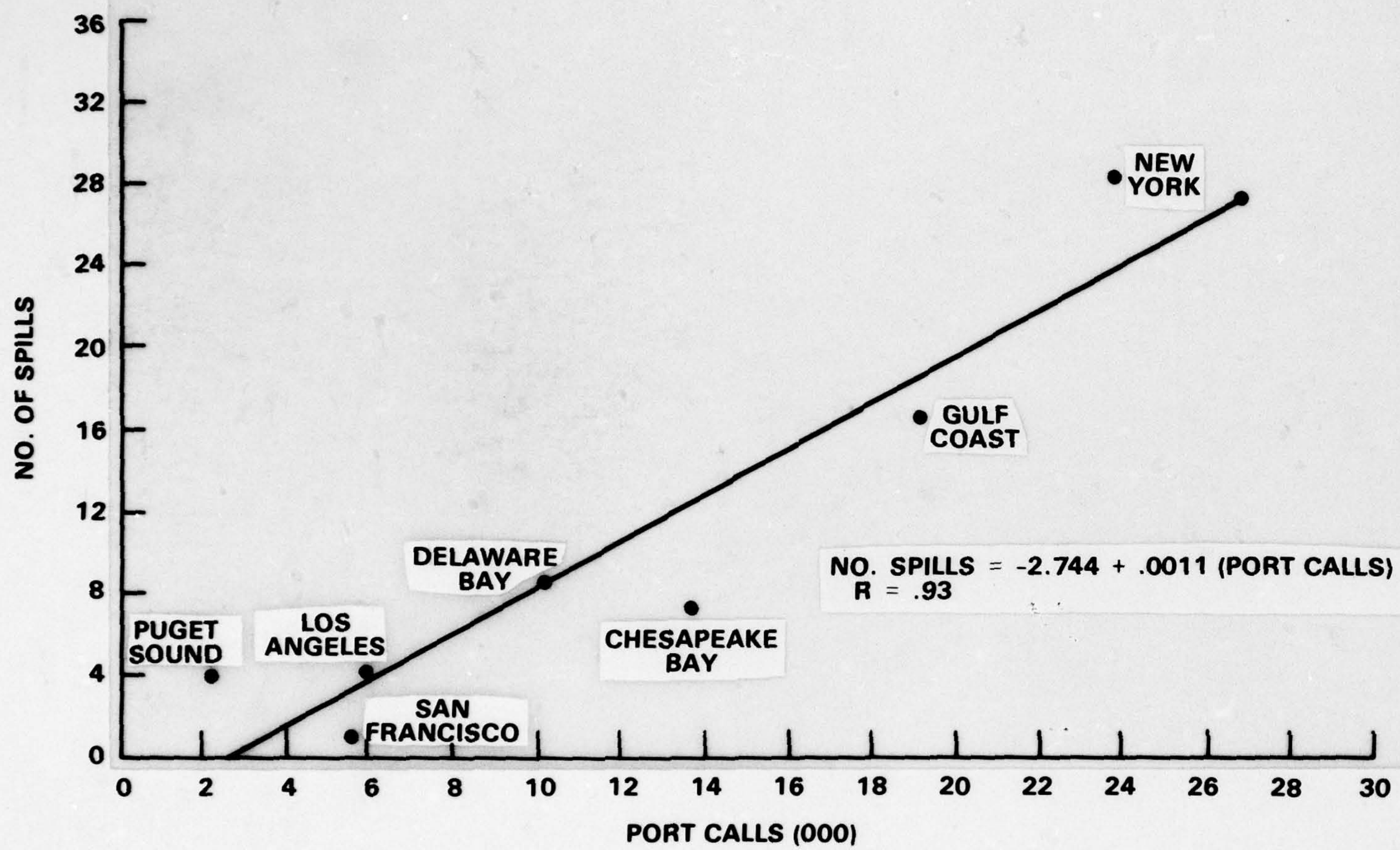

FIGURE IV-17. TANKER SPILL RESULTING FROM A CASUALTY VS. TOTAL PORT CALLS IN 7 MAJOR PORT SYSTEMS 1973-1976

foreign and domestic crude oil and petroleum products brought into each of the ports during the 1973-1976 period.

The volume spilled was once again calculated from the PIRS data. The total spillage was calculated for each port system by adding the amount spilled by all oil carrying tankers as a result of a casualty. In cases where PIRS records potential spillage, that amount was not included in the total.

The result of this analysis showed that there is a strong relationship between volume spilled and volume throughput. A plot of the actual points and the regression line can be seen in figure IV-18. The regression equation is:

amount spilled (000 gals) = -552,418 + .0057 (volume throughput)

$R = .97 \quad R^2 = .93$

In summary, the series of regressions described above show strong relationships between port calls and number of impact casualties; vessel age and non-impact casualties; port calls and number of spills; and volume throughput and volume spilled.

D. Weather Data

1. Introduction

The purpose of this appendix is to discuss the weather and currents in the Gulf of Mexico, its approaches, the Caribbean Sea, and the local weather and currents in the vicinity of LOOP and SEADOCK in order to assess how the operation of these two deepwater ports will be affected. Although both weather and current will have a direct effect on vessel operations in general, and selection of routes in particular, these aspects will not be discussed in any depth, since they are covered under the paper transit and actual ship transits sections of Chapter VI, "Hazard Identification and Ranking." In like manner, weather broadcasts will not be discussed in this section since they are treated in the companion report on Technology/Service Alternatives.[1]

A detailed treatment of weather patterns and currents in the Gulf of Mexico and its approaches is contained in appendix F of this report. This section will discuss the relationships between weather and vessel operations, and how the operation of LOOP and SEADOCK will be affected by weather.

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1. PRC Systems Services Company, Deepwater Ports Approach/Exit - Control/Capabilities Assessment - Technology/Service Alternatives (prepared for the U.S. Coast Guard, February 1979).

(43) (112)

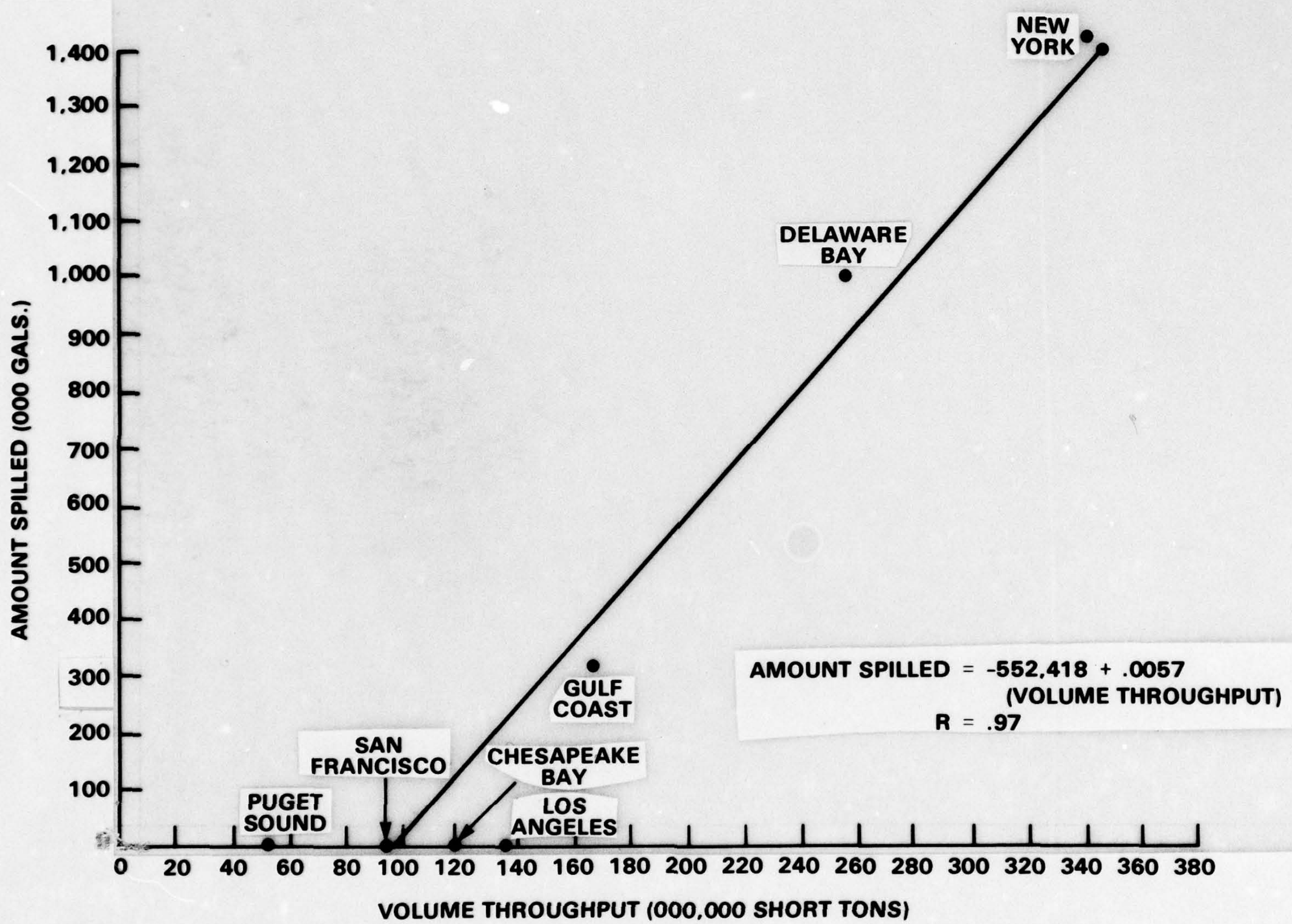

FIGURE IV-18. CRUDE OIL AND PETROLEUM PRODUCTS VOLUME THROUGHPUT VS. AMOUNT SPILLED IN SEVEN MAJOR PORT SYSTEMS 1973-1976

113

2. Weather

a. General

The forecasting and dissemination of weather has an important and frequently vital application to shipping, aviation, hydrology, agriculture and other human activities. The World Meteorological Organization (WMO), a specialized agency of the United Nations, maintains a worldwide coordinated network of government and commercial radio stations which broadcast weather reports for the important water areas of the world, using a variety of emissions, whose purpose is to give the mariner timely and accurate weather forecasts vital to safe navigation.

b. Weather Dissemination System

In the United States, this program is administered by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration, Department of Commerce. Through agreements, NWS provides weather reports to selected government and commercial radio stations for dissemination to the public. Information concerning the entire system of marine weather broadcasts is contained in "Worldwide Marine Weather Broadcasts" published by the National Weather Service.[1] Weather broadcasts of interest to vessels operating in the Gulf of Mexico and Caribbean Sea have been extracted from this publication and other sources, and appear in the companion report on Technology/Service Alternatives,[2] together with times, frequencies, emissions, area of coverage and type of broadcast (that is, analysis and storm warnings, for example). No attempt has been made in this study to assess the effectiveness of the weather dissemination system, or the adequacy of the weather reports; however, the number of stations transmitting weather, the comprehensive nature of the weather broadcasts, the frequent and complementary scheduling, and the number of types of radio emissions, suggests that the Gulf of Mexico, the Caribbean Sea and approaches to those bodies of water have thorough radio broadcast coverage.

c. Description of Proposed Limits on LOOP Operations

The LOOP pumping platform complex (PPC) will have a completely integrated weather and sea state data gathering system. National Weather Service and private weather service reports can be received by teletype at the PPC. Weather and sea state data will be communicated to the ships to assist the

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1. U.S. Department of Commerce, Worldwide Marine Weather Broadcasts (Silver Spring, Maryland: National Weather Services, 1977).
2. PRC Systems Services Company, Deepwater Ports Approach/Exit - Control/Capabilities Assessment - Technology/Service Alternatives (prepared for the U.S. Coast Guard, February 1979).

master in his approach to LOOP. Prior to boarding an incoming ship, the mooring master will gather the latest information on currents, and local weather conditions, in addition to any other information which may influence the safe berthing and offloading of the tanker.[1]

The following operational limits based on weather conditions are planned by LOOP:[2]

- Tanker mooring operations will be limited to sea conditions not exceeding 6-foot significant seas. Mooring launches, personnel launches, and work boats will stay at the port for inspection and other essential services in sea conditions up to 12-foot significant seas.
- Hook-up of hoses will not be permitted in sea conditions exceeding 6-foot significant seas.
- Pumping of cargo will not be allowed to continue if sea conditions exceed 12-foot significant seas.
- Disconnection of hoses will be required if sea conditions exceed 12-foot significant seas and the storm is still building.
- Tankers will be required to depart the SPM in conditions exceeding:
  - 15-foot significant waves;
  - sustained winds of 50 mph;
  - currents exceeding 3.0 feet/second aligned with a 45 mph wind, or 2.0 feet/second perpendicular to a 45 mph wind.
- Bunkering operations and fueling of the pumping platform complex will be terminated if sea conditions exceed 5-foot significant seas.
- The complete shut-in of all systems and evacuation of port will take place when it is predicted that the center of a hurricane will pass within 180 miles of

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1. U.S. States Coast Guard, Final Environmental Impact/4(f) Statement LOOP Deepwater Port License Application, Volume 1 (Washington, D.C.: Office of Marine Environment and Systems, 1976), pp. 1-59 and 1-117.
2. Op Cit., p. 1-121.

the port. When such a hurricane is forecast to be within 36 hours of the port, the superintendent will consult with LOOP management before orders to "secure and evacuate for hurricane" are initiated.

d. Description of Proposed Limits on SEADOCK Operations[1]

Weather information will be obtained from contract weather services with data received at the pumping platform complex by periodic voice communications or facsimile. Telex/TWX systems and a National Weather Service receive only teletype will be considered for the control center, both offshore and onshore. Private weather service reports can be received over the commercial system. Furthermore, a National Weather Service Facsimile terminal will be considered for control center locations to permit reception of weather maps.

Standard weather monitoring equipment will be installed at the platform complex. Additionally, the offshore terminal will measure wave, current, and sea temperature. Indicating and recording equipment will be located at the control center.[2]

The following operational limits based on weather conditions are planned by SEADOCK:[3]

- The mooring launches will be limited in tanker mooring operations to sea conditions not exceeding 6- to 8-foot seas. Mooring launches, personnel launches and work boats will stay at the port for inspection and other essential services in sea conditions up to 12-foot significant seas. Operations experience will dictate changes in this planning as may be required.
- No mooring of a tanker to an SPM is undertaken in sea conditions exceeding 6-foot significant seas.
- Hook-up of hoses will not be permitted in sea conditions exceeding 6-foot significant seas.

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1. Texas Deepwater Port Authority estimates their revised startup time to be 1982. The analysis in this report is based on the 1976 SEADOCK EIS and may not precisely correspond to the final plans of the successor port.
2. U.S. Coast Guard, Final Environmental Impact Statement SEADOCK Deepwater Port License Application, Volume 1 (Washington, D.C.: Office of Marine Environment and Systems, 1976), p. 1-61.
3. Op Cit., p. 1-116.

- Pumping of cargo will not be allowed to be initiated in sea conditions exceeding 6-foot significant seas.
- Pumping of cargo will not be allowed to continue if sea conditions exceed 12-foot significant seas.
- Disconnection of hoses will be required if sea conditions exceed 12-foot significant seas and the storm is still building, or if the mooring load monitor indicates loads reaching 75 percent of the safe working load of the mooring.
- Tankers will be required to depart the SPM in sea conditions exceeding:
  - 15-foot significant waves;
  - if mooring loads approach the safe working load of the hawser.
- The complete shutdown of all systems and the evacuation of the port will take place when it is predicted that a storm poses a definite threat to the facility. When such a storm is forecast to be within 36 hours of the port, the superintendent will consult with SEADOCK management before orders to "secure and evacuate for hurricane" are initiated.

e. Discussion of Weather Influence on DWP Operations

Table IV-22 summarizes the weather operating limits at LOOP and SEADOCK, which are specified above, and are taken from the respective Environmental Impact Statements.[1,2] Table IV-22 also shows how often these limits are exceeded based upon the historical weather data contained in appendix F. The most frequent interference to deepwater port operations appears to be in the oil transfer operation, where 5- to 6-foot sea limitations are placed on the bunkering,

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1. U.S. Coast Guard, Final Environmental Impact/4(f) Statement LOOP Deepwater Port License Application, Volume I (Washington, D.C.: Office of Marine Environment and Systems, 1976), p. 1-121.
2. U.S. Coast Guard, Final Environment Impact Statement SEADOCK Deepwater Port License Application, Volume I (Washington, D.C.: Office of Marine Environment and Systems, 1976), p. 1-116.

Table IV-22 Weather Operating Limits at LOOP and SEADOCK

Operations	Weather Limit LOOP	Percent of Time Limit Exceeded LOOP (summer to winter)	Weather Limit SEADOCK	Percent of Time Limit Exceeded SEADOCK (summer to winter)
o Tanker Mooring Launch Assistance	≤ 6' seas	5 to 25%	≤ 6-8' seas	9.3 to 25%
o Mooring launches, Personnel launch and Work Boat for inspection purposes	≤ 12' seas	0.2 to 2.9%	≤ 12' seas	0.2 to 2.7%
o Hook-up of hoses	≤ 6' seas	5 to 25%	≤ 6' seas	5 to 25%
o Begin pumping cargo	≤ 6' seas	5 to 25%	≤ 6' seas	5 to 25%
o Continue pumping cargo	≤ 12' seas	0.2 to 2.9%	≤ 12' seas	0.2 to 2.7%
o Disconnect hoses	> 12' seas, and storm building	0.2 to 2.9%	> 12' seas, and storm building, or mooring load monitor > 75% of safe working load.	Unknown, but seas 0.2 to 2.7%
o Tanker depart SPM	> 15' seas or	0.2 to 2.9%	> 15' seas or	< 1%
	sustained winds of 50 mph, or	< 0.2%	if mooring loads approach	Unknown
	current > 3.0 ft/sec. aligned with 45 MPH wind, or	Unknown, but wind < 1%	safe working load	
	current 2.0 ft/sec. perpendicular to 45 MPH wind	Unknown, but wind < 1%		
o Termination of bunkering operations and fueling of PPC	> 5' seas	11 to 37%	*	*
o Complete shut-down and evacuation of port	Hurricane predicted to pass within 180 miles in 36 hours	Once every 4.1 years	Hurricane definite threat in 36 hours	Once every 3.2 years

* No limit specified.

tanker mooring, hose hook-up, and commencement of pumping functions (transfer system accidents are outside the scope of this study). The ranges given in the columns "Percent of Time Limit Exceeded" represent seasonal variations with the worst conditions occurring during the winter months. During this period some 30 to 40 polar air masses penetrate the Gulf of Mexico from the North American Continent. A large number (15 to 20) of these masses bring strong northerly winds, which are called "northers." Winds from 25 to 50 knots or more may occur in severe northers. Areas close to the coast, such as the LOOP and SEADOCK safety zone areas, do not have heavy seas during these northers, since the wind is offshore and the seas have an insufficient fetch to allow generation of large seas. In the offshore areas, however, these cold blasts from the continent become very unstable as they spread south over the warmer sea generating squally conditions which may cause considerable havoc. The force of northers usually decreases south of the Yucatan Channel, but in the open waters of the Gulf of Mexico they are capable of causing considerable damage to shipping several times a year during the winter months, with high winds, heavy swells and rough seas.[1] Vessels transiting the Gulf of Mexico and the LOOP and SEADOCK safety fairways will be exposed to the full force of these storms, whose winds at times exceed 50 knots.

A further hazard to deepwater port operation in the Gulf of Mexico is the tropical cyclone during the period June through October. The tropical cyclone from 34 to 63 knots is called a tropical storm, from 64 to 108 knots, a hurricane, and 109 knots or greater, an intense hurricane. In the LOOP area, a tropical storm has occurred once every 1.6 years, a hurricane once every 4.1 years, and an intense hurricane, once every 48 years. In the SEADOCK area, a tropical storm has occurred once every 2.1 years, a hurricane once every 3.2 years, and intense hurricane every 28 years.[2,3] According to the guidelines, both LOOP and SEADOCK would close down and evacuate for a hurricane. At LOOP, tankers would

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1. British Admiralty, East Coasts of Central America and Gulf of Mexico Pilot, N.P. No. 69A, First Edition, 1970 (Taunton, Somerset, England: Hydrographer of the Navy, 1970), p. 48.
2. U.S. National Oceanic and Atmospheric Administration, Environmental Guide for the U.S. Gulf Coast (Asheville, North Carolina: National Climatic Center, 1972), pp. 40 and 77.
3. U.S. National Oceanic and Atmospheric Administration, Environmental Guide for Seven U.S. Ports and Harbor Approaches (Asheville, North Carolina: National Climatic Center, 1972), pp. 90 and 106.

depart the SPMs in sustained winds of 50 mph, and under certain combinations of current force and direction and winds of 45 miles per hour. At SEADOCK, no wind limitations have been set, only sea state (15 feet) and mooring loads.

f. Discussion of Weather Influence on Vessel Operations

Vessels proceeding in the Gulf of Mexico to and from LOOP and SEADOCK will be exposed several times during the winter months to the northers, which as previously described can cause them severe damage in the open waters of the Gulf with high winds, heavy swells, and rough seas.

In the preceeding section, frequencies of occurrence of tropical storms and hurricanes were specified for both the LOOP and SEADOCK areas. Since the tankers using these ports will be moving through the Caribbean Sea and the Gulf of Mexico, however, rather than occupying a fixed location, their exposure to hurricanes will be higher than that of the two deepwater ports. According to the American Meteorological Society:[1] "In a typical year in the open Atlantic, just north of the equator, about 100 "seedling" disturbances will form. About ten of these will become potential hurricanes as they approach the Caribbean region. Six of these reach hurricane state, that is, sustained winds of 64 knots or more. An average of two will strike the U.S. mainland as full-blown hurricanes." As tankers proceed through the Caribbean enroute to and returning from LOOP and SEADOCK, these powerful storms pose a catastrophic threat to their safety. Being present in a ship of any size at sea during the passage of a hurricane is an awesome experience. Mariners who have survived this experience will go to great lengths to avoid its repetition in the future. Large vessels may receive heavy damage, and smaller ships may break up. (For a description of the passage of a hurricane at sea, see appendix F.)

Although modern methods of surveillance provide accurate positions of tropical storms and hurricanes, there are still substantial errors in forecast positions. For example, the 24-hour 75 percent forecast error is about 150 nautical miles, while the 48-hour and 72-hour forecast errors are about 300 and 400 nautical miles, respectively.[2] A tanker in LOOP or SEADOCK given 36-hour notice of the approach of a hurricane cannot be certain of its forecast position within

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1. "Policy Statement of the American Metereological Society on Hurricanes," Volume 54, Number 1, Bulletin of the American Meteorological Society (Boston, Massachusetts: American Meteorological Society, January 1973), pp. 46 and 47.
2. A. L. Crutcher and R. G. Quayle, Mariners Worldwide Climatic Guide To Tropical Storms At Sea (Washington, D.C.: U.S. Government Printing Office, 1974), p. 29.

about 225 miles, or 14 to 15 hours steaming time of a 15- to 16-knot vessel. The prudent master should always maintain a plot of storm locations when operating in an area subject to tropical storms, in order to ensure his vessel is not trapped in an area with insufficient sea room to permit him to evade storm damage. The key to successful storm evasion is early action. Sometimes, however, the mariner may find his evasion route to the open sea blocked, and in this case minimizing the effect of the storm is the only reasonable course. For a discussion of the general maneuvering rules to reduce hurricane damage and a description of several vessel weather routing systems, see appendix F to this report.

g. Discussion of the Influence of Current on Vessel Operations

Although currents have been the cause of a number of vessel casualties in the Gulf of Mexico, many have been due to the failure to consider currents in maneuvering, resulting in collisions and rammings. A thorough knowledge of major ocean currents, on the other hand, can actually permit the mariner to use them to his benefit to shorten, or at least not impede his passage. Later in this study (see section VI.A.1 -- Paper Transit of Vessel Routes Into and Out of the Gulf of Mexico) an analysis is made of ways in which vessels may use currents to their advantage in the Gulf of Mexico and Caribbean Sea. Appendix F to this study contains descriptions of major currents affecting vessel transit to and from LOOP and SEADOCK and current patterns in the vicinity of those two deepwater ports.

h. Discussion of Low Visibility

Sea fog in the Gulf of Mexico is very rare. Visibility may, however, be reduced below fog limits during heavy rainstorms which accompany tropical cyclones. Coastal fog does occur year around in both the LOOP and SEADOCK areas with the least occurrence in summer and the greatest in winter and early spring. In the LOOP area, the foggiest months are January through March (3.1 to 4.2 percent frequency) while in the SEADOCK area the worst visibility is from October through April (2.7 to 6.4 percent frequency).

V. OIL SPILL RISK PREDICTION

A. General Discussion

The risks of oil spills caused by accidents involving the tankers using the deepwater port facilities are evaluated in this section. Spills within the Gulf of Mexico and the Gulf entrances are considered over the first 30 years of operation of the ports. The quantitative assessment of the oil spill risks will provide a basis for determining the need for risk-mitigating measures for deepwater port operations and will serve as the baseline against which such measures can be evaluated.

Risks are measured in terms of the expected number of casualties resulting in spills, the probability distribution for the total amount spilled over a given time period, and the probability of at least one spill of size greater than a specified amount occurring during a given time period. The primary inputs for these measures are the spill frequency and spill size distributions based upon historical data.

The risks of tanker oil spills for deepwater port operations are difficult to predict with any degree of confidence because of the lack of directly applicable data. There are no existing deepwater ports operated by the United States and those operated by other nations have little pertinent casualty history. Further, no reliable analytic or simulation models exist for estimating the spill or casualty probabilities in terms of the appropriate system parameters. Consequently, the analysis described in this section is based upon use of surrogate data--historical oil spill data from tanker operations in environments judged to be similar to those of the deepwater ports. In selecting the appropriate surrogate environments for the various portions of the deepwater port transit, we have attempted to be conservative in our assumptions. If the safety measures planned for the deepwater ports are strictly adhered to, the risks may be much less than predicted. However, based upon past experience of tanker operations, the implementation of such safety measures does not necessarily imply adherence. Thus, for example, it is not assumed that the tankers always sail within the boundaries of the safety fairway, since the fairways are voluntary rather than compulsory.

The estimation of the risks associated with deepwater ports and the projection of those risks over a 30-year period is based upon the assumption that deepwater port operations do not differ significantly, as far as oil spill risks are concerned, from other tanker operations and that these risks will vary with time only as a result of the increase in tanker traffic to the ports. Certain differences such as less likelihood of grounding and use of SPMs rather than piers are taken into consideration to reduce the estimated risks, however. This is done by eliminating certain casualties from the data utilized for the analysis, as will be seen.

For purposes of the risk evaluation, the deepwater port transits considered include the entries into the Gulf of Mexico via the Straits of Florida, Old Bahama Channel, and Yucatan Channel; the Gulf open sea; the safety fairways, the traffic separation schemes, and the safety zones containing the SPMs, pumping platform and control platform.

B. Spill Data Utilized

The three vessel casualty files discussed in section IV were considered for the spill risk analysis. The Vessel Casualty Reporting System (VCRS) does not contain spill size data. To utilize this data base, casualty rates would have to be developed from the data and conditional spill rates given a casualty had occurred would have to be obtained from another source. Further, the VCRS includes only casualties in U.S. waters (generally within the three-mile limit) plus a few casualties involving U.S. vessels in foreign waters.

The Pollution Incident Reporting System (PIRS) does contain spill size data. However, the spills recorded are those occurring in U.S. waters, within the three-mile limit. The primary problems with the PIRS data, as discussed in section IV-A, are the relative unreliability and limited area of coverage.

The Tanker Casualty File (TCF) contains data on tanker casualties and spills. It is not restricted to any location or country of registry and includes size estimates for most of the spills. In addition, the TCF contains information on the location of the spill--pier, harbor, harbor entrance, coastal, or open sea--which is useful in relating historical casualty data to the deepwater port problem, as will be shown.

The portion of the deepwater port transits of concern in this analysis includes only the Gulf and Gulf entrances, whereas the TCF data reflect worldwide casualties. Statistical tests were performed to determine if there were significant differences between Gulf and worldwide spill data. Only 23 of 578 spills included in the TCF (all tankers) occurred in the Gulf area. The test applied is the standard chi-square test of independence for contingency tables. The data and test results are shown in tables V-1 and V-2. The tests address the question of independence between Gulf and worldwide spill data, where independence implies that the relative frequencies of spills by casualty type or location type are not dependent on the region of the spill (Gulf or worldwide). In other words, the null hypotheses being tested are (1) relative spill frequencies by casualty type do not differ between regions, and (2) relative spill frequencies by location type do not differ between regions. The standard level of significance of 5 percent is used in the tests. The worldwide data exclude the Gulf data so the sets are disjoint. Further, since a casualty may fall within only one location type category and one casualty type category and since no biases are

Table V-1. Comparison of Gulf and Worldwide
Oil Spill Rate by Casualty Type

Oil Spill Incidents

Area	Collisions	Rammings	Groundings	Breakdowns	Structural Failures	Fires	Explosions	Capsizing	Total
Gulf & Carribean	9	2	3	2	4	1	2	0	23
World	190	90	148	12	99	26	41	12	578

Degrees of Freedom = 7

$\chi^2_{7,\,.05} = 14.1$

χ^2 (data) = 7.4

Conclusion: Accept null hypothesis that relative spill incident frequencies by casualty type do not differ between World and Gulf data at the 95% confidence level.

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125

Table V-2. Comparison of Gulf and Worldwide Oil Spill Data by Location Type

Oil Spill Incidents

Area	Coastal	Harbor Entrance	Harbor	Pier	Open Sea	Total
Gulf & Carribean	2	4	10	3	4	26
World	174	95	124	68	104	565*

Degrees of Freedom = 4

$\chi^2_{4,\,.05} = 9.5$

χ^2 (data) = 8.9

Conclusion: Accept null hypothesis that relative spill frequencies by location type do not differ between World and Gulf data at the 95% confidence level.

*Unknown location incidents excluded.

evident in the data, the process is assumed to be random. Thus, the criteria of the chi-square test are satisfied.

The results shown in tables V-1 and V-2 indicate that the null hypothesis is accepted in each case; that is, that there is no significant difference between worldwide and Gulf data as far as location type or casualty type is concerned. Thus, we have no reason to restrict our data base only to Gulf spills.

As discussed in section II, during the initial operation of the deepwater ports, the expected tanker sizes range from 50,000 to 500,000 deadweight tons. The spill sizes differ among vessels of different capacities. Table V-3 shows the mean spill sizes for various size tankers based on 249 spills recorded in the 1969-1973 Tanker Casualty File. Clearly, there is a significant difference between vessels less than 20,000 DWT and those greater than 20,000 DWT. Most of the spills (70 percent) for tankers above 20,000 DWT are for tankers in the 20,000-60,000 DWT range, for which the mean spill size is triple that for tankers less than 20,000 DWT. The variation among the higher ranges can be ascribed primarily to the smaller sample sizes. Therefore, to reflect the types of tankers expected for the deepwater port operation, the data used in the spill risk analysis exclude tankers less than 20,000 DWT.

In summary, the data for the spill frequency and size analysis are based on Tanker Casualty File data for tankers greater than 20,000 DWT operating worldwide.

C. Spill Frequency Computation

Impact casualties (collisions, rammings, and groundings) and nonimpact casualties (structural failures, breakdown, fires, explosions, and capsizings) are treated separately in the risk analysis. As shown in section IV.C, a strong relationship has been established between spill frequency and port calls for impact casualties. No such relationship appears to exist for nonimpact casualties. Thus, port calls are used as the exposure variable for impact casualties, with certain modifications discussed below.

Since no significant relationships are evident between nonimpact spill rate and such exposure variables as port calls or time in port, the most straightforward exposure variable is used: tanker-days in transit and loading/unloading.

The distinction between impact and nonimpact spill rate treatment arises from the different causal factors between these categories. Generally, collisions, rammings, and groundings are related to traffic congestion, restricted maneuvering area, currents and tides, and other navigational problems. Personnel fault is a significant factor in these casualties. Nonimpact casualties, on the other hand, are generally related to weather conditions, structural failure, and equipment failure. Mitigation of impact casualty risks

Table V-3. Average Spill Sizes by Vessel Size Group

Vessel Size (DWT)	Number	Mean Spill Size (Long Tons)
< 20,000	130	1,852
20,000 - 39,999	59	6,101
40,000 - 59,999	25	5,524
60,000 - 79,999	9	2,394
80,000 - 99,999	8	2,971
100,000 - 124,999	-	14,969
125,000 - 149,999	-	-
150,000 - 199,999	-	-
200,000 - 249,999	-	-
250,000 - 299,999	-	-
300,000 - 349,999	9	4,069
≥ 350,000	-	-
All Vessels	249	3,837

Table V-4. Average Spill Sizes by Cumulative Vessel Size Group

Vessel Size	Number	Mean Spill Size (Long Tons)
All Vessels	249	3,837
≥ 20,000 DWT	119	6,006
≥ 40,000 DWT	60	5,913
≥ 60,000 DWT	35	6,190
≥ 80,000 DWT	26	7,504
≥ 100,000 DWT	18	9,519
≥ 125,000 DWT	9	4,069
≥ 150,000 DWT	9	4,069
≥ 200,000 DWT	9	4,069
≥ 250,000 DWT	9	4,069
≥ 300,000 DWT	9	4,069
≥ 350,000 DWT	-	-

can be addressed by various navigational safety measures such as traffic separation schemes, vessel traffic services, personnel training and licensing, communications procedures, vessel locations systems, etc. The main thrust of the deepwater port analysis is the evaluation of oil spill risks and the assessment of navigational measures to reduce these risks. Since impact casualties are generally related to navigational problems, while nonimpact casualties are not, they are analyzed separately throughout the remainder of this section. The final results combine the two casualty types to yield total risks.

The regression analysis presented in section IV demonstrated a strong linear relationship between impact casualties and tanker port calls. Recall that the analysis considered port systems, each of which included several individual ports with a large variety of geometric configurations, traffic density, climates, etc.

The casualties occurred within the harbors, at the piers, or along the coast between harbors. The rationale for the regression relationship is that the port calls represent exposure to the primary hazards that can lead to collisions, rammings, and groundings, such as traffic congestion, obstructions, shallow depths, etc. The open sea, where these hazards occur infrequently, has correspondingly less impact casualties. This can be seen from table V-5, which summarizes tanker spill frequencies from the Tanker Casualty File. Over 60 percent of the nonimpact casualties occurred at sea, while only 4 percent of the impact casualties occurred at sea. Since most of the tanker operational time is at sea it follows that while tanker-days may be a reasonable exposure parameter for nonimpact casualties, it is not useful for estimating impact casualty rates.

The PIRS data on which the regression relationship between spills and port calls is based indicate 67 impact spills for about 78,500 port calls or .00085 spills per port call. The TCF data shown in table V-5 indicate 153 impact spills during 1969-1973 for tankers greater than 20,000 DWT. From section IV, the estimated number of port calls for tankers in this category over this period was 212,900. This results in a rate of 0.00072 spills per port call. Applying the standard statistical test for difference in proportions[1] results in the conclusion that the difference of 0.00013 is not significant at the 5 percent level of significance (the 95 percent confidence interval for the difference is between -0.00009 and 0.00035). Since the TCF represents a larger data base and since in allows breakdown of the

1. Wilfred Dixon and Frank Massey, Jr., Introduction to Statistical Analysis, McGraw-Hill, York, PA, 1951, p. 195.

Table V-5. Oil Spill Data from Tanker Casualty File

	Location Type						
Casualty Type	Coastal	Harbor Entrance	Harbor	Pier	Open Sea	Unknown	Total
Collision	28	13	19	3	5	2	70
Ramming	2	2	8	8	1	1	22
Grounding	27	17	15	1	0	1	61
Total Impact	57	32	42	12	6	4	153
Breakdown	1	1	1	0	0	1	4
Structural Failure	3	1	2	2	34	2	44
Fire	0	0	0	4	2	0	6
Explosion	4	0	0	1	7	0	12
Capsizing	1	0	0	1	1	0	3
Total Non-Impact	9	2	3	8	44	3	69
Total (Impact & Non-Impact)	66	34	45	20	50	7	222

Note: Spills are from tankers greater than 20,000 DWT during 1969-1973. One long ton spills excluded.

95%

data into location and casualty types, these data are used in the impact casualty rate computations.

In order to estimate impact spill rates by transit zone, surrogate location types from TCF were used. Nonimpact spill rates are estimated by transit zone on the basis of tanker-days within each zone.

The TCF location types are defined as follows:

- o entrance - entrance to a harbor, bay, river, etc.
- o harbor - within the boundaries of a harbor, bay, river, etc.
- o pier - moored at a pier, dock, wharf, etc.
- o coastal - within 50 nautical miles of shoreline
- o at sea - more than 50 nautical miles from shoreline

Straits and channels, including the Straits of Florida, Old Bahama Channel, and Yucatan Channel, are equated with the TCF location category of coastal regions. As shown in table V-5, collisions and groundings are the most likely spill casualty types in these regions. The Gulf of Mexico from the straits and channels to the safety fairways is comparable to the TCF open sea category. Nonimpact casualties predominate in this region, particularly structural failures.

There are no exact surrogates in the data base for the safety fairway, traffic separation scheme zone, and safety zone. The LOOP and SEADOCK safety fairways are lanes leading to the deepwater ports in which no obstructions such as oil drilling rigs can be built (see figures II-2 and II-4). If the tankers stay within the lanes, rammings should not occur, except possibly with floating debris. However, the tankers are only advised, not required, to stay within the safety fairway. Experience with existing safety fairways in the Gulf indicates that tankers often ignore them to follow shorter routes. Therefore, both rammings and collisions were considered for the safety fairways. Groundings were excluded because the depth in the areas of the fairways are sufficiently large, with the single exception of the Flower Garden Bank near the SEADOCK fairway. While this bank represents a distinct hazard, it is not felt that it significantly alters the overall casualty probability for this region.

The traffic separation scheme (TSS) comprises the last two miles to the safety zone. Current planning indicates that this scheme will involve one way traffic. If this is followed by all ships, it will eliminate meeting collisions. However, it is possible that ships

other than the DWP tankers will cross this zone, which could result in meeting collisions. Thus, in the interest of conservatism, all types of collisions were considered in this zone. The casualty rates for the safety fairway and TSS zone were estimated by equating these zones with harbor entrances, excluding groundings.

The safety zone casualties were estimated by applying harbor casualty data excluding groundings. Groundings were excluded because of the large depths in the safety zones (105-115 feet for LOOP and about 100 feet for SEADOCK). It is possible, but highly unlikely, that a tanker with an extremely deep draft (say, over 90 feet) could ground if it were to go off course in the vicinity of the safety zone. However, likelihood of this seems sufficiently small so that it can be ignored in this analysis. Rammings with the buoys, structures, and moored vessels are possible in the safety zone as are collisions with other vessels. Impact casualties occurring at the piers were excluded because the use of SPMs is expected to represent significantly less hazard than piers.

Table V-6 summarizes the assignment of surrogates to transit zones. The casualty frequencies are obtained from the TCF data shown in table V-5.

Two distributional forms were considered for spill frequency--the Poisson and the negative binomial. The Poisson distribution applies to situations where the events occur randomly and independently in time. The parameter characterizing the Poisson distribution is the intensity parameter, usually denoted as λ. The Poisson probability distribution for oil spills is expressed as:

$$P(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \qquad (1)$$

where:

t = future exposure (time or port calls)

λ = spill rate per unit of t

n = number of spills

If the spill frequency distribution consists of a mixture of Poisson distributions, each with intensity values that are themselves distributed according to a gamma distribution with both parameters equal to zero, the result is a negative binomial distribution.[1] This

1. Samuel Kotz, Discrete Distributions, Houghton Mifflin Company, Boston, 1969.

Table V-6. Surrogate Transit Zones

Transit Zone	TCF Location Type	Casualty Types Excluded	Number of Casualties	Percentage
Straits and Channels	Coastal		57	54
Gulf, Open Sea	Open Sea		6	6
Safety Fairway and Traffic Separation Scheme	Harbor Entrance	Groundings	15	14
Safety Zone	Harbor	Groundings	27	26
TOTAL			105	100
Unknown Location (prorated)			3	
TOTAL			108	

theoretical framework could apply to the spill frequency problem since spills occur from several different casualty types, each of which may behave according to a Poisson process. This concept was applied by Devanney and Stewart[1] in an analysis of oil spills off the U.S. Atlantic Coast and Gulf of Alaska. The negative binomial formulation is:

$$f(n) = \binom{n + N-1}{N-1} \left(\frac{t}{T+t}\right)^n \left(\frac{T}{T+t}\right)^N \qquad (2)$$

where:

n = number of spills

N = past number of spills

T = past exposure over which the spills occurred

t = future exposure

The number of parameters can be reduced to two by letting $\alpha = t/T$.

The two distributional forms were tested against the TCF spill frequency data to determine the best fit. The data were analyzed in terms of spills per month separately for impact and nonimpact spills. The chi-squared results are summarized in table V-7. Both distributions satisfy the chi-square criterion for goodness of fit at the 95 percent probability level (level of significance = 0.05). However, the negative binomial represents a slightly better fit in each case, based on the chi-square probability value. This value for the negative binomial represents the probability that if the true distribution is the negative binomial, the test of a random sample of the specified size will yield a chi-square value at least as large as the computed chi-square value. It is, in effect, a quantification of the confidence that the distribution being fitted is the true distribution from which the sample data were taken. Since this parameter value is slightly larger for the negative binomial distribution, this distribution was used in the analysis.

1. J.W. Devanney III and Robert J. Stewart, "Bayesian Analysis of Oil Spill Statistics," presented at the January 1974 meeting of the New England Section of the Society of Naval Architects and Marine Engineers.

Table V-7. Goodness of Fit Results for Spill Frequency

Distribution	Casualty Type	Computed χ^2 Value	Degrees of Freedom	χ^2 Probability	5 Percent χ^2 Value
Poisson	Impact	5.29	4	.26	9.49
	Non-Impact	5.12	3	.18	7.81
Negative Bionmal	Impact	4.52	4	.40	9.49
	Non-Impact	2.66	2	.42	5.99

The spill rates for impact and nonimpact casualties are given in table V-8 below:

Table V-8 Spill Rate Values

Casualty Type	Past Exposure	Number of Spills	Spill Rate
Impact	212,900 port calls	108	.00051/port call
Nonimpact	4,033,000 tanker-days	69	.000017/tanker-day

The past exposure values are taken from section IV.B and the spill frequencies from table V-5 for nonimpact spills and table V-6 for impact spills. The value of 108 spills for impact casualties represents the 153 spills shown in table V-5 less groundings in harbor and harbor entrances and all impact casualties at piers.

The expected number of spills during each five-year period of operation for LOOP and SEADOCK are given in tables V-9 and V-10. The values are based on the spill rates of table V-8 and future exposure rates from tables IV-14 and IV-15.

The impact casualty rates are prorated among the transit zones according to the corresponding percentages from table V-6. The nonimpact casualty rates are prorated on the basis of time within each zone. The largest contributor to the casualty rate appears to be impact casualties in the straits and channels (5.2 expected casualties for LOOP and 7.8 expected casualties for SEADOCK over 30 years) followed by impact casualties in the safety zone (2.5 and 3.7 expected casualties for LOOP and SEADOCK, respectively). Together these two elements comprise 70 percent of the expected casualties. Impact casualties in all zones account for over 85 percent of the total expected casualties, with a rate of over 5 times the nonimpact casualty rate. The casualty frequencies are higher for SEADOCK than for LOOP because the estimated traffic for the former is much higher. Further, nonimpact casualties are relatively higher for SEADOCK than LOOP because of the longer transit distances. Of the expected impact casualties in the straits and channels about one-half are collisions and one-half are groundings based upon the data of table V-5. Less than 4 percent are rammings.

D. Spill Size Distributions

The distributions of spill sizes indicate a large number of small spills and a very few large spills with the range between the smallest and largest being extremely large.

The data used in this analysis include 88 impact and 31 nonimpact spills from the Tanker Casualty File (TCF). These spills represent those resulting from casualties involving tankers larger than 20,000 DWT. Spills recorded as 1 long ton were excluded because this

Table V-9. Expected Number of Spills for LOOP by Transit Zone, Casualty Type, and Time Period

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	.535	.055	.136	.254	.98
	Non-Impact	.007	.079	.012	.032	.13
	Total	.542	.134	.148	.286	1.21
1985-1989	Impact	.720	.074	.183	.341	1.32
	Non-Impact	.010	.109	.016	.045	.18
	Total	.730	.183	.199	.386	1.50
1990-1994	Impact	.860	.088	.219	.408	1.58
	Non-Impact	.013	.133	.021	.054	.22
	Total	.873	.221	.240	.462	.1.80
1995-1999	Impact	.985	.101	.251	.467	1.80
	Non-Impact	.015	.151	.023	.062	.25
	Total	1.000	.252	.274	.529	2.05
2000-2004	Impact	1.060	.109	.270	.503	1.94
	Non-Impact	.016	.163	.025	.067	.27
	Total	1.076	.272	.295	.570	2.21
2005-2009	Impact	1.060	.109	.270	.503	1.94
	Non-Impact	.016	.163	.025	.067	.27
	Total	1.076	.272	.295	.570	2.21
1980-2009	Impact	5.218	.535	1.328	2.475	9.56
	Non-Impact	.076	.791	.120	.324	1.31
	Total	5.294	1.326	1.448	2.799	10.87

Table V-10. Expected Number of Spills for SEADOCK by Transit Zone, Casualty Type, and Time Period

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	.908	.093	.231	.431	1.66
	Non-Impact-	.015	.200	.020	.055	0.29
	Total	.923	.293	.251	.486	1.95
1985-1989	Impact	1.207	.124	.307	.573	2.21
	Non-Impact	.020	.269	.026	.074	0.39
	Total	1.227	.393	.333	.647	2.60
1990-1995	Impact	1.386	.142	.353	.658	2.54
	Non-Impact	.024	.310	.031	.086	0.45
	Total	1.410	.452	.384	.744	2.99
1995-1999	Impact	1.386	.142	.353	.658	2.54
	Non-Impact	.024	.310	.031	.086	0.45
	Total	1.410	.452	.384	.744	2.99
2000-2004	Impact	1.411	.145	.359	.669	2.58
	Non-Impact	.024	.317	.031	.083	0.46
	Total	1.435	.462	.390	.752	3.04
2005-2009	Impact	1.475	.151	.376	.700	2.70
	Non-Impact	.025	.331	.032	.092	0.48
	Total	1.500	.482	.408	.792	3.18
1980-2009	Impact	7.773	.797	1.979	3.687	14.24
	Non-Impact	.132	1.730	.069	.480	2.51
	Total	7.905	2.527	2.048	4.167	16.75

value is used in the TCF to denote a minimum size spill, which could be as small as 1 gallon. Also excluded from the data are spills whose sizes were computed based on the average for the appropriate casualty type, rather than directly estimated. Inclusion of these spills would result in a large concentration of spill sizes around certain values which would not reflect the true situation. The spill size data are summarized in table V-11.

In order to utilize the spill size data in projections of the expected amount spilled over a specified period of time, the data should be smoothed. This was accomplished by fitting three distribution functions to the spill size data: log normal, gamma, and inverted gamma. Each of these distributions has been applied previously to spill size distributions for oil spill analyses. For example, the gamma was used in a study by BDM for the Office of Technology Assessment[1] and the log normal by A.D. Little in the LOOP and SEADOCK environmental impact statements,[2,3] They have been used because each of them can, with the appropriate parameter values, represent data that are highly skewed towards smaller values, as is the case for oil spills.

The distributions were fitted separately to the impact and nonimpact spill data. The parameter values for each were estimated by the maximum likelihood method. For the gamma and inverse gamma distributions, this method results in means and standard deviations that match the sample means and standard deviations, respectively. However, the maximum likelihood method applied to the log normal distribution does not generally yield means and standard deviations that match the sample values.

The probability density functions and the parameter values for the three distribution functions used for impact and nonimpact spills are:

1. Office of Technology Assessment, Coastal Effects of Offshore Energy Systems, Volume II, U.S. Congress, November 1976.

2. U.S. Coast Guard, Final Environmental Impact Statement, LOOP Deepwater Port License Application, Department of Transportation, 1976.

3. U.S. Coast Guard, Final Environmental Impact Statement, SEADOCK License Application, Department of Transportation, 1976.

Table V-11. Spill Size Data

Range (Long Tons)	Impact Casualties	Non-Impact Casualties
1-1,000	56	9
1,001-2,000	12	1
2,001-3,000	4	2
3,001-4,000	5	2
4,001-5,000	1	1
5,001-6,000	3	4
6,001-7,000	1	0
7,001-8,000	0	1
8,001-9,000	0	0
9,001-10,000	0	0
10,001-15,000	2	0
15,001-20,000	1	2
20,001-25,000	0	2
25,001-30,000	0	1
30,001-35,000	0	5
35,001-40,000	1	1
>40,000	2	0
Total	88	31

Log normal

$$f(x) = \frac{1}{x \; 2\pi\sigma} \exp\left(-(\ln x - \mu)^2/2\sigma^2\right) \quad (3)$$

Impact	μ	=	6.42
	σ	=	2.08
Nonimpact	μ	=	7.59
	σ	=	3.01

Gamma

$$f(x) = \frac{x^{\alpha-1}\beta^{\alpha}e^{-\beta x}}{\Gamma(\alpha)} \quad (4)$$

Impact	α	=	0.356
	β	=	.0000885
Nonimpact	α	=	0.376
	β	=	.0000323

Inverted Gamma

$$f(x) = \frac{1}{\Gamma(\alpha)^{\beta}} e^{\frac{-1}{\beta x}} \left(\frac{1}{\beta x}\right)^{\alpha+1} \quad (5)$$

Impact	α	=	1.1
	β	=	0.0025
Nonimpact	α	=	1.115
	β	=	0.000747

Figures V-1 and V-2 present the cumulative distribution curves for each of the distributions for impact and nonimpact casualties, respectively. One statistical model for comparing fits is the chi-square (χ^2) goodness-of-fit test. This test is based upon the differences between the theoretical and actual values of frequencies of spill sizes. It can be

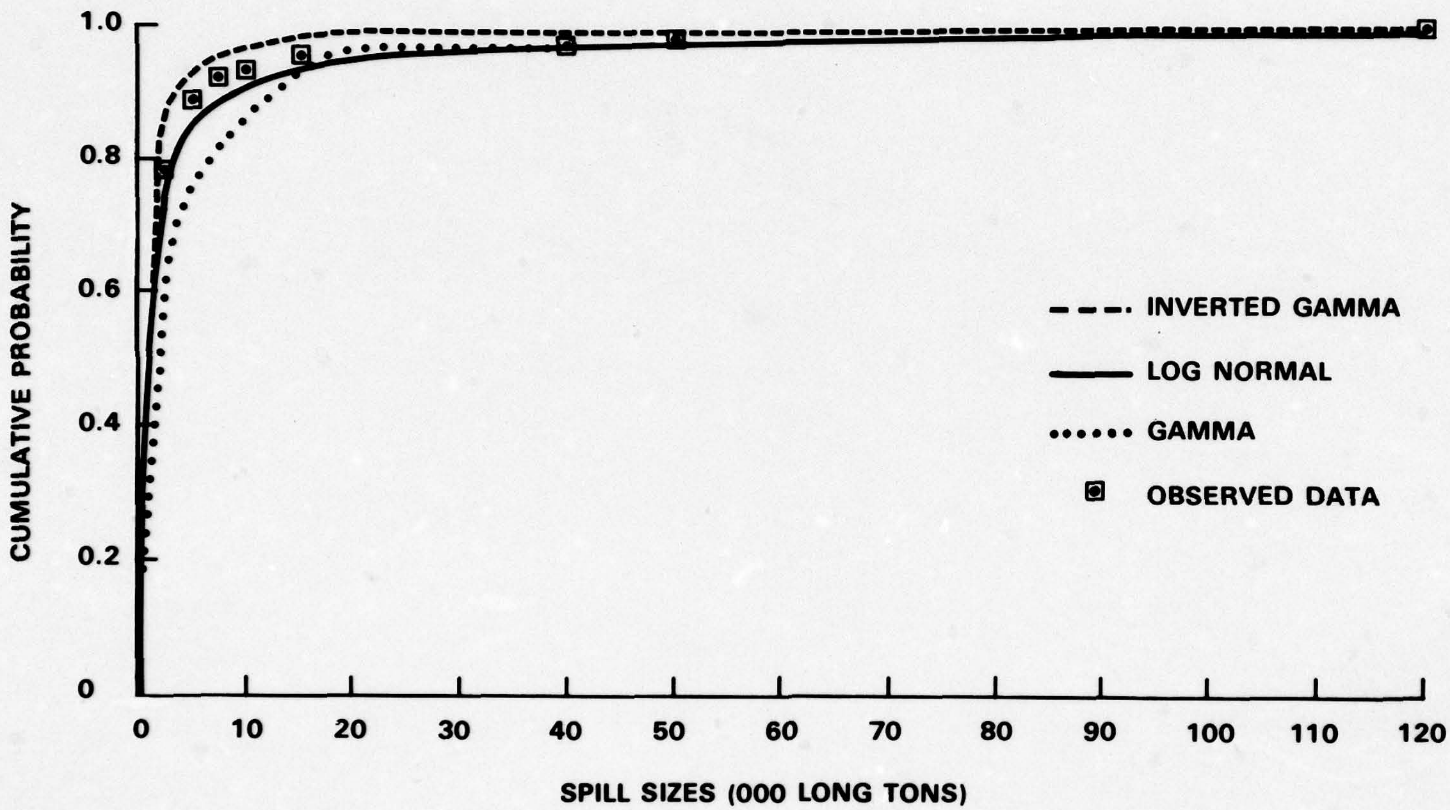

FIGURE V-1. ACTUAL AND FITTED CUMULATIVE DISTRIBUTIONS OF IMPACT CASUALTY SPILL SIZES

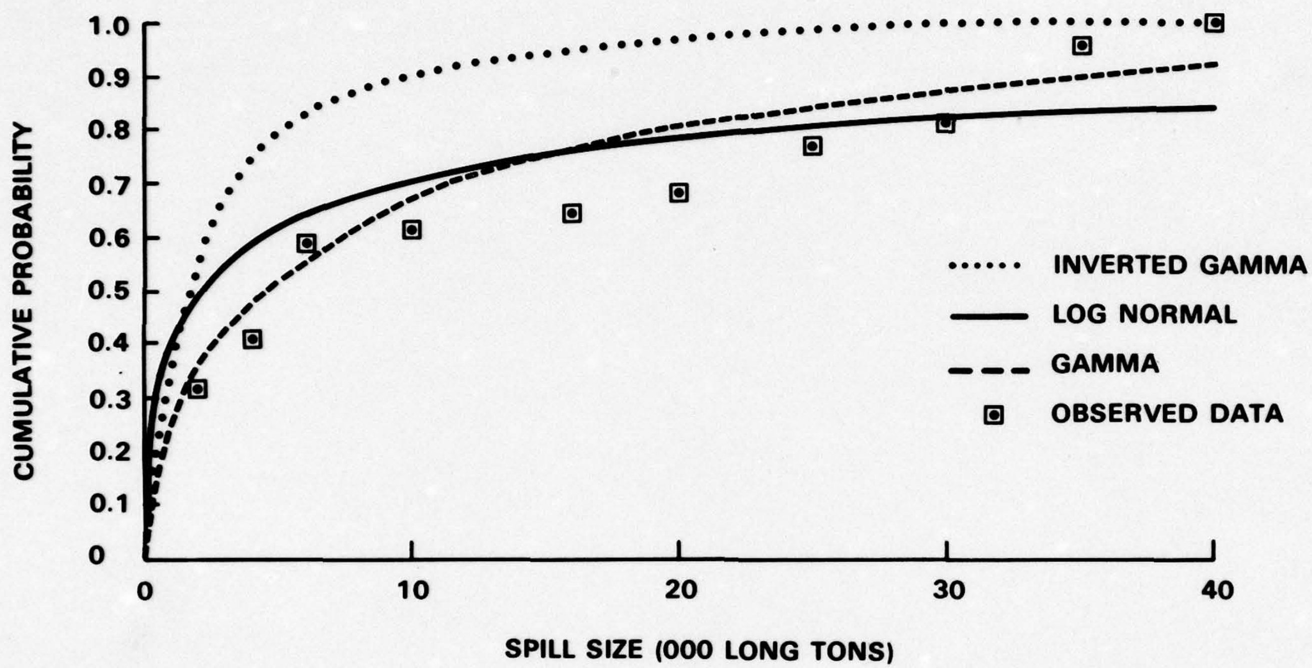

FIGURE V-2. ACTUAL AND FITTED CUMULATIVE DISTRIBUTIONS OF NON-IMPACT SPILL SIZES

used to test the null hypothesis, H_o, that the distribution function being tested, $F_o(x)$, (e.g., the gamma distribution) is the true distribution from which the sample data were drawn. The level of significance of the test, p is the probability of rejecting the hypothesis when it is true. To test H_o for a given distributional fit to a set of data, the computed chi-square value, χ^2_c, is compared with the chi-square value at a specified level of significance, χ^2_p. If χ^2_p is exceeded, H_o is rejected; otherwise it is accepted. The value of p is arbitrary, depending upon the desires of the user; generally, values of .05 are used.

There is a probability value p associated with each χ^2_c value, based upon the degrees of freedom (equal to the number of cells into which the data are grouped minus one for distributions whose parameters are derived from the original rather than the grouped data). This probability can be interpreted as the probability that, if H_o is true (that is, if the true distribution is $F_o(x)$), a series of random samples of specified size from that distribution would result in a chi-square value as large as χ^2_c 100 p percent of the time. Expressing it another way, p = .05 means that we may be five percent confident that the observed data is distributed according to $F_o(x)$. Conversely, we would be 95 percent confident that we do not know the form of the distribution.

The chi-square values for the three fitted distributions are presented in table V-12 along with the chi-square values corresponding to various p values. None of the distributions represent good fits. For impact casualty spills, each distribution is acceptable at the 0.001 level of significance but not at the 0.005 level. For nonimpact casualties spills, both the log normal and the gamma distribution are accepted at the 0.05 level of significance while the inverted gamma is rejected for all levels shown. The gamma is the best fit of the three for nonimpact spills.

The results of the chi-square tests do not indicate a high level of confidence that the distributions analyzed are very good representations of the two distribution spills sizes. It is possible that the fits could be improved by applying more complex statistical processes; however, this would incur a significant increase in computational difficulty. Further, even if such processes were pursued, the value gained is questionable because of the relative paucity of data on major spills.

The relatively poor fits are not unexpected because highly skewed distributions such as represented by the oil spill data characteristically do not display high confidence fits to standard distributions. However, referring to the cumulative plots of figures V-1 and V-2, the log normal and gamma distributions appear reasonably close to the observed data. Further, the tails of the log normal distributions are significantly larger than those of the

Table V-12. Spill Size Curve Fit Data for Log Normal, Gamma, and Inverted Gamma Distributions

Casualty Type	Distribution	Computed Chi-Square	Degrees of Freedom	Chi-Square Values .05	.005	.001
Impact	Log Normal	24.7	9	16.9	23.6	27.9
	Gamma	21.8	9	16.9	23.6	27.9
	Inverted Gamma	18.1	5	11.1	16.8	20.5
Non-Impact	Log Normal	16.4	9	16.9	23.6	27.9
	Gamma	4.7	5	11.1	16.8	20.5
	Inverted Gamma	33.2	3	7.8	12.8	16.3

gamma; consequently, there is a higher estimated probability of very large spills using the former. The data, which cover the period from 1969 to 1973, contain few large spills (the largest is 120,000 tons); however, there have been several spills of 100,000 tons or more since 1973. It is felt that the log normal reflects the probability of such spills more conservatively than does the gamma. In view of the above considerations, the log normal distribution was selected as a nonrigorous but analytically convenient description for the oil spill size distribution for risk estimation purposes.

The log normal function was also fit to spill size distributions for the individual casualty categories--collisions, rammings, groundings, etc. The resulting parameter values are given in table V-13. The variances of the distributions are quite large, as evidenced by the large values of the coefficients of variation (standard deviation divided by the mean). Another indication of the wide variation is that the range for impact spill sizes is about 30 times the mean. The maximum spill size recorded in the data--120,300 tons--accounts for 30 percent of the total amount spilled.

E. Spill Risk Prediction

1. Total Amount of Oil Spilled over a Specified Period

One of the primary risk measures of interest is the predicted volume of oil spilled from deepwater port operations over specified time periods. To develop this estimate requires both the spill frequency and spill size distributions. The total volume is simply the sum of the sizes of the individual spills over the period. Probabilistically any number of spills can occur and the size of each individual spill will vary according to the appropriate distribution.

If there are n spills over a period and each spill is of size x_i, the total volume spilled is

$$y_n = \sum_{i=1}^{n} x_i \qquad (6)$$

However, both n and the x_i's are random variables. Denoting the probability density function (pdf) of y_n by $g(y_n)$ and the pdf of n by p (n), the pdf for volume spilled is:

$$v(x) = \sum_{n=o}^{\infty} p(n)\, g(y_n) \qquad (7)$$

Table V-13. Tanker Casualty Spill Size Statistics by Type of Casualty

Casualty Type	Number	Spill Size (long tons) Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation (%)
Collision	37	4,424	19,656	5	120,300	444
Grounding	40	4,489	9,826	10	49,209	219
Ramming	11	981	871	10	3,000	89
Total Impact	88	4,023	14,304	5	120,300	355
Breakdown	1	408	-	408	408	-
Capsizing	2	27,334	9,426	20,669	34,000	34
Explosion	12	7,815	9,150	5	31,716	117
Fire	1	500	-	500	500	-
Structural Failure	15	14,088	14,938	4	40,000	106
Total Non-Impact	31	11,635	13,092	4	40,000	112

where:

$v(x)$ = probability density for x amount spilled

$p(n)$ = probability of n spills

$g(y_n)$ = probability density for y_n amount spilled given n spills

The pdf $g(y_n)$ is derived from the pdf for the x's, f(x), by means of the n-fold convolution on f(x), denoted by $f^{n*}(x)$. Thus equation 7 becomes:

$$v(x) = \sum_{n=o}^{\infty} p(n)\, f^{n*}(x) \tag{8}$$

This formulation, termed the Collective Risk Model,[1,2] has been applied in actuarial analyses. For that application, the input random variables are the number of claims and the claim sizes and the resulting random variable is total amount of the claims over a given period.

Recall that p(n) is the negative binomial distribution and f(x) is the log normal. The convolution of the log normal with itself does not result in an analytically tractable problem. Consequently, a Monte Carlo simulation technique was used to estimate v(x). This approach is detailed in appendix A.

Sample sizes of 500 were used to generate the spill volume distributions. Figures V-3 through V-8 depict the cumulative probability distributions for oil spillage over a 30-year period for LOOP and SEADOCK. The histograms for amount spilled by 5- and 30-year periods are given in appendix A. The median and 90th percentile values (in long tons) of the distributions are as follows:

	Median	90th Percentile
LOOP		
impact	23,800	93,400
nonimpact	1,400	73,700
combined	38,600	180,100
SEADOCK		
impact	40,900	136,400
nonimpact	15,000	163,300
combined	75,400	282,800

The expected amounts spilled by time period, casualty type, and transit zone are presented in tables V-14 and V-15. These results are based upon the average spill

1. H. Cramer, Collective Risk Theory, Skandia Insurance Company, 1955.

2. Ove Lundberg, On Random Processes and Their Application to Sickness and Accident Statistics, Uppsala, 1964.

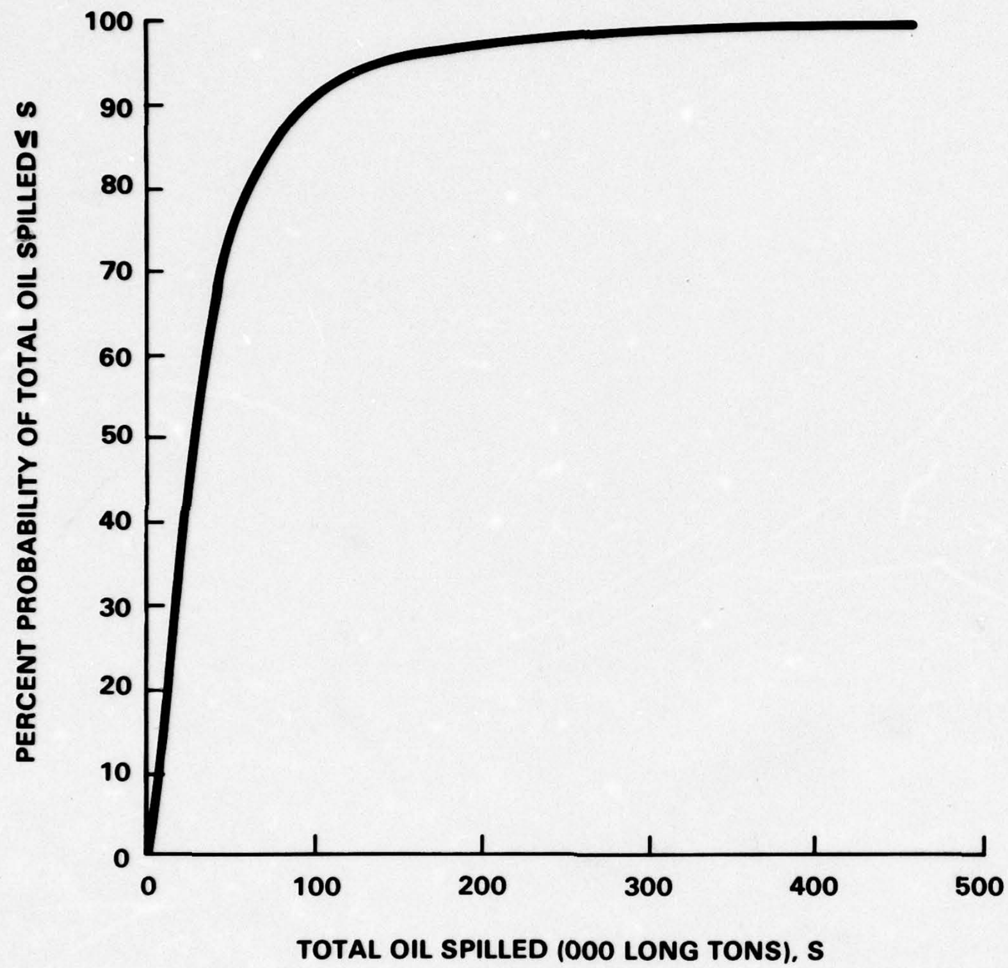

FIGURE V-3. LOOP: CUMULATIVE PROBABILITY OF TOTAL OIL SPILLED FOR IMPACT CASUALTIES 1980-2009

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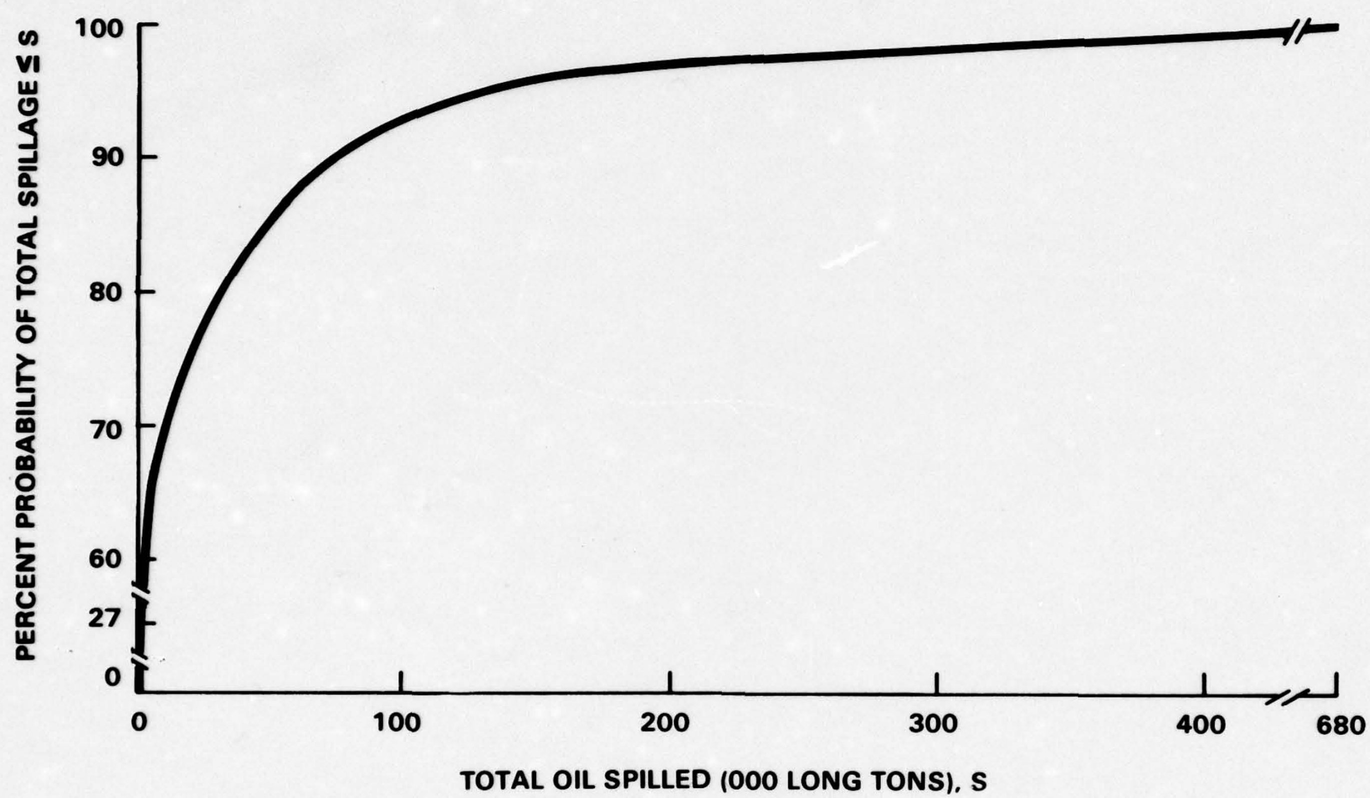

FIGURE V-4: LOOP: CUMULATIVE PROBABILITY OF TOTAL OIL SPILLED FOR NON-IMPACT CASUALTIES 1980-2009

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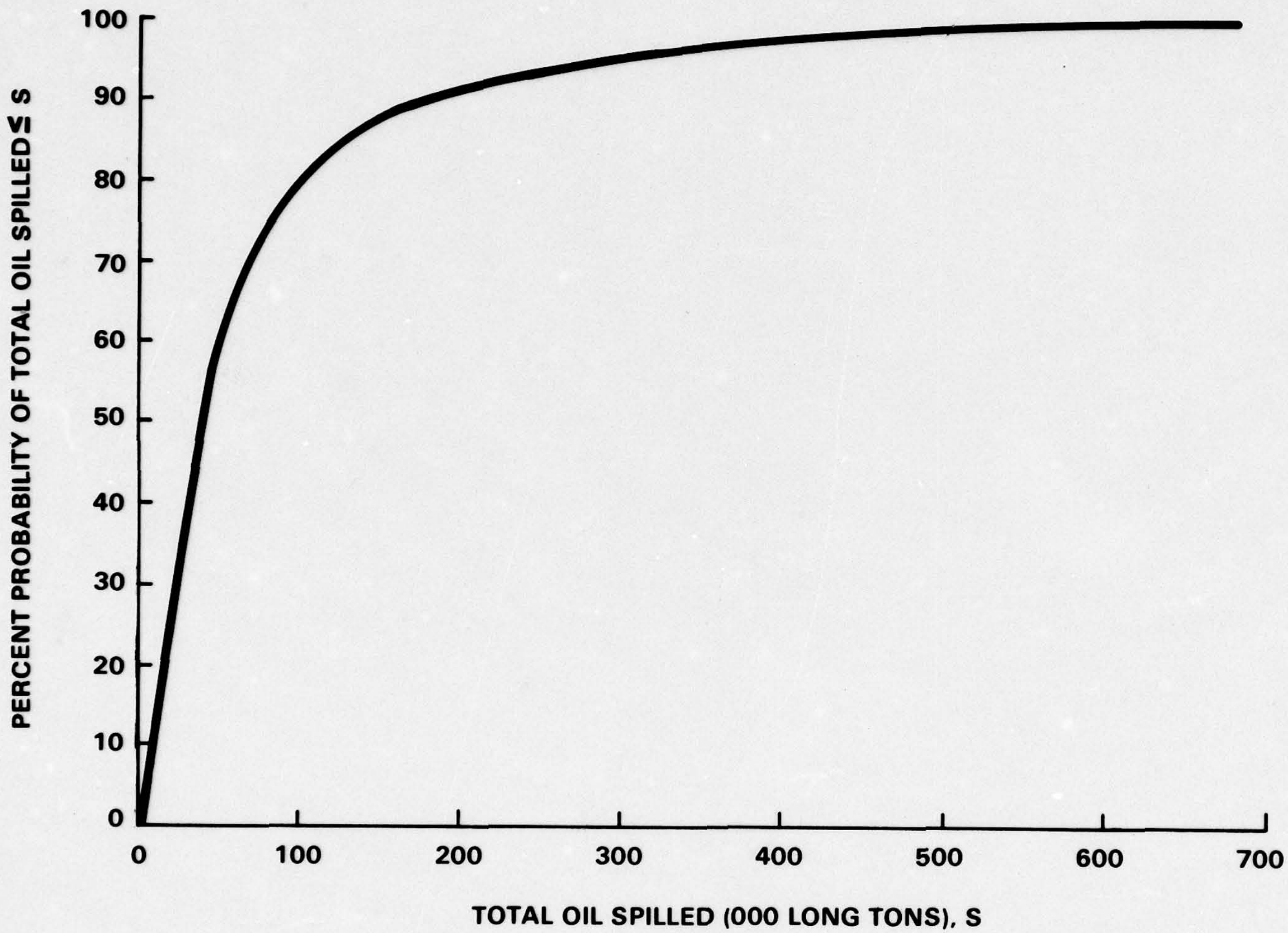

FIGURE V-5. LOOP: CUMULATIVE PROBABILITY OF TOTAL OIL SPILLED 1980-2009

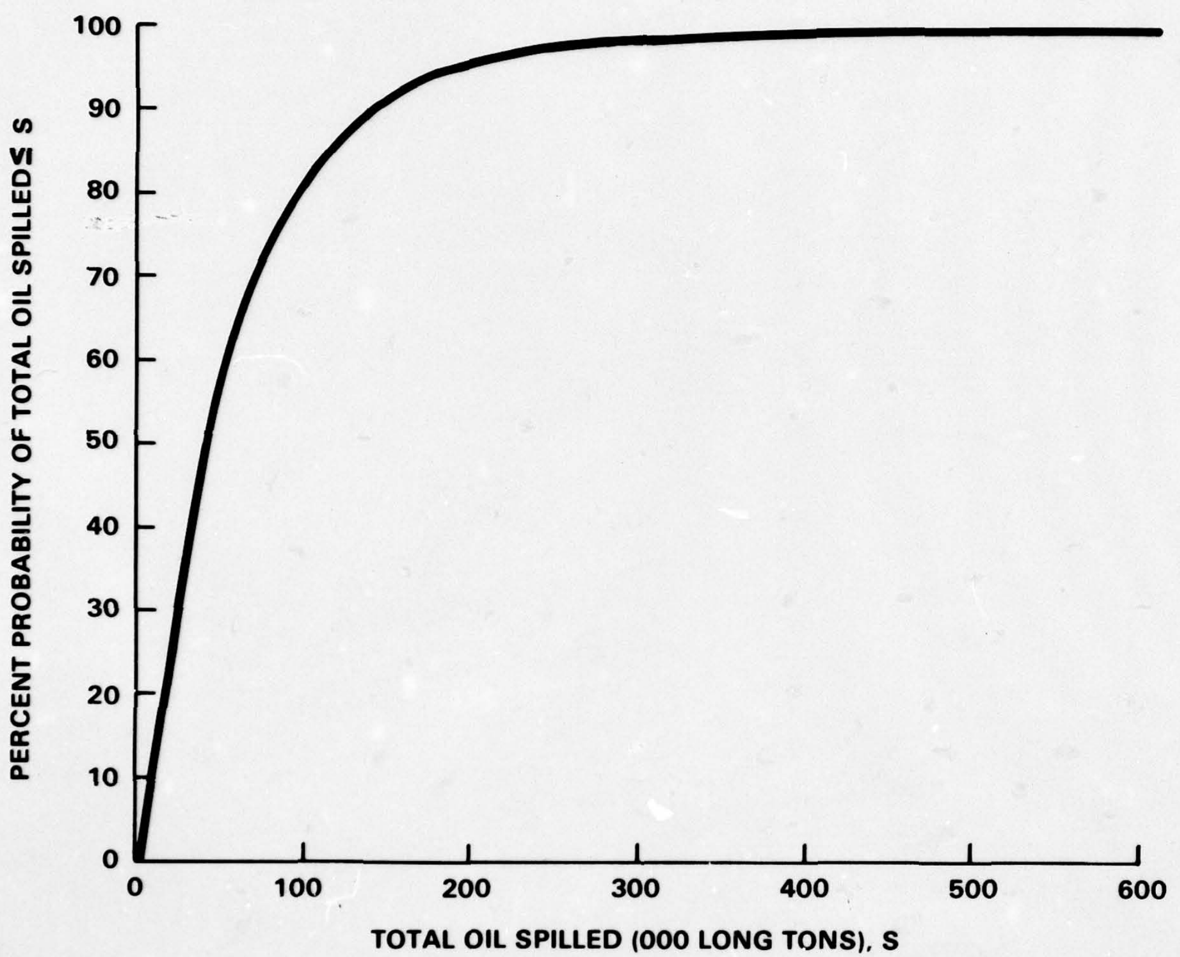

FIGURE V-6. SEADOCK: CUMULATIVE PROBABILITY OF TOTAL OIL SPILLED FOR IMPACT CASUALTIES 1980-2009

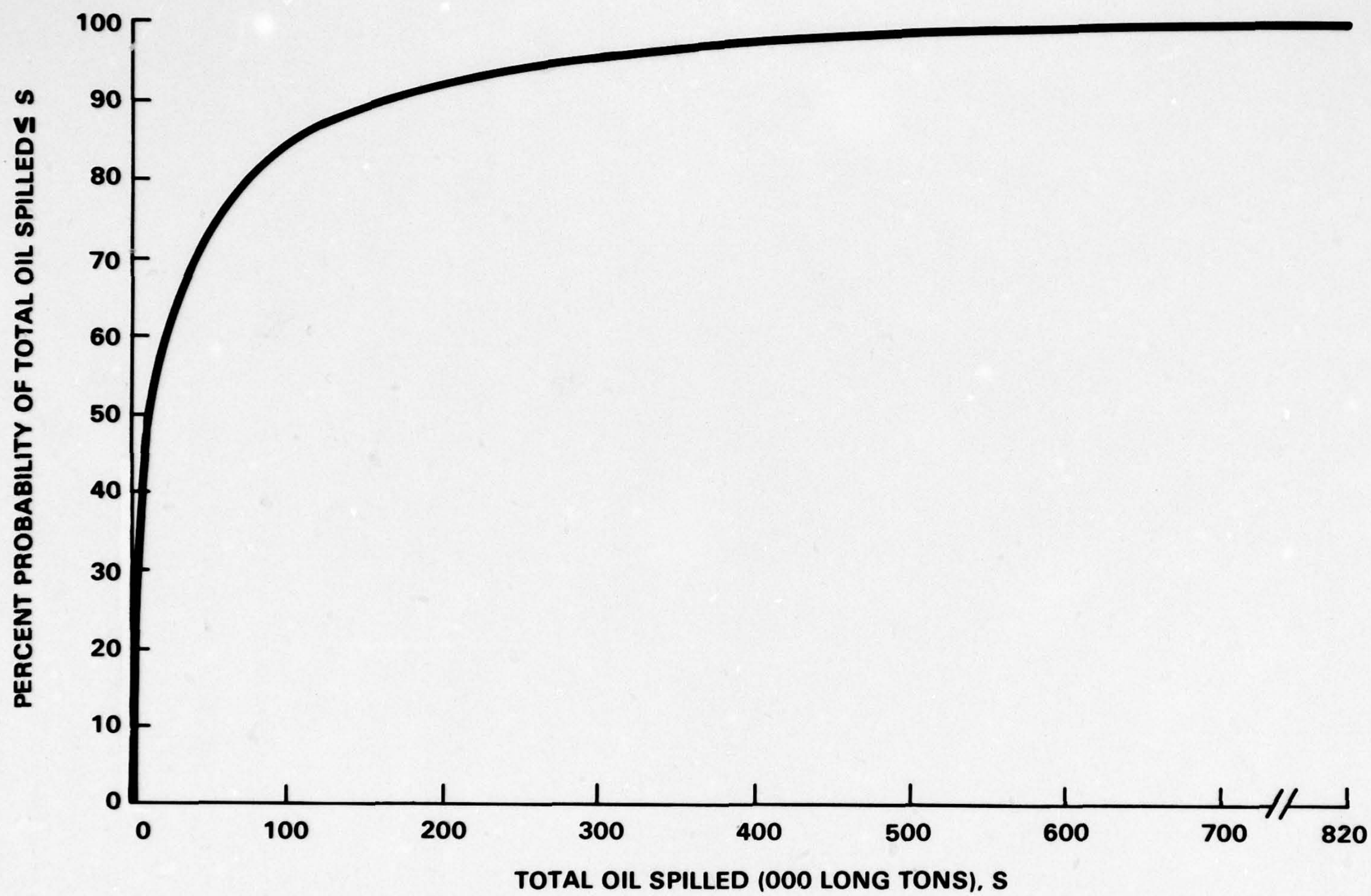

FIGURE V-7. SEADOCK: CUMULATIVE PROBABILITY OF TOTAL OIL SPILLED FOR NON-IMPACT CASUALTIES 1980-2009

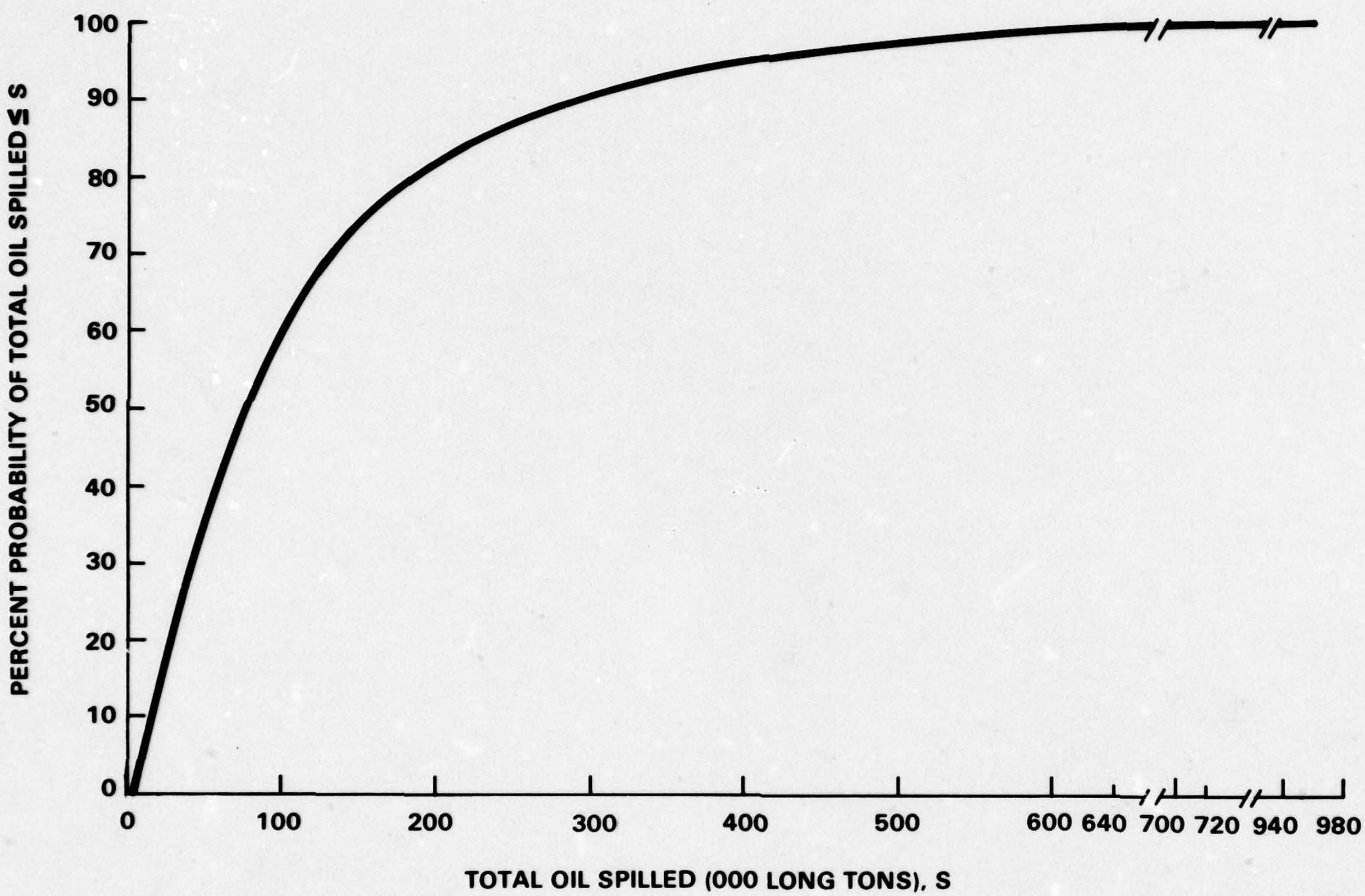

FIGURE V-8. SEADOCK: CUMULATIVE PROBABILITY OF TOTAL OIL SPILLED 1980-2009

Table V-14. Expected Amount Spilled for LOOP by Transit Zone, Casualty Type, and Time Period

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	2,141	220	545	1,016	3,921
	Non-Impact	90	939	142	384	1,555
	Total	2,231	1,159	687	1,400	5,476
1985-1989	Impact	2,897	297	737	1,374	5,305
	Non-Impact	122	1,270	191	519	2,103
	Total	3,019	1,567	928	1,893	7,408
1990-1994	Impact	3,463	355	882	1,643	6,343
	Non-Impact	146	1,519	229	621	2,515
	Total	3,609	1,874	1,111	2,264	8,858
1995-1999	Impact	3,967	407	1,010	1,882	7,266
	Non-Impact	167	1,470	262	712	2,881
	Total	4,134	2,147	1,272	2,594	10,147
2000-2004	Impact	4,261	437	1,085	2,021	7,804
	Non-Impact	179	1,869	282	764	3,094
	Total	4,440	2,306	1,367	2,785	10,898
2005-2009	Impact	4,261	437	1,085	2,021	7,804
	Non-Impact	179	1,869	282	764	3,094
	Total	4,440	2,306	1,367	2,785	10,898
1980-2009	Impact	20,991	2,153	5,344	9,957	38,445
	Non-Impact	884	9,206	1,387	3,765	15,242
	Total	21,875	11,359	6,731	13,722	53,687

Note: Sums may not equal total due to rounding since individual table values were derived by allocating percentages of the totals to each zone. Values in long tons.

Table V-15. Expected Amount Spilled for SEADOCK by Transit Zone, Casualty Type, and Time Period

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	3,659	375	931	1,736	6,701
	Non-Impact	181	2,354	229	653	3,417
	Total	3,840	2,729	1,160	2,389	10,118
1985-1989	Impact	4,847	497	1,234	2,299	8,877
	Non-Impact	240	3,119	303	865	4,527
	Total	5,087	3,616	1,537	3,164	13,404
1990-1994	Impact	5,566	571	1,417	2,64	10,195
	Non-Impact	275	3,581	348	993	5,198
	Total	5,841	4,152	1,765	3,634	15,393
1995-1999	Impact	5,566	571	1,417	2,641	10,195
	Non-Impact	275	3,581	348	993	5,198
	Total	5,841	4,152	1,765	3,634	15,393
2000-2004	Impact	5,692	584	1,449	2,700	10,424
	Non-Impact	282	3,662	356	1,015	5,315
	Total	5,974	4,246	1,805	3,715	15,739
2005-2009	Impact	5,942	609	1,513	2,818	10,882
	Non-Impact	294	3,823	372	1,060	5,549
	Total	6,236	4,432	1,885	3,878	16,431
1980-2009	Impact	31,272	3,207	7,961	14,834	57,274
	Non-Impact	1,548	20,122	1,957	5,578	29,204
	Total	32,820	23,329	9,918	20,412	86,478

Note: Sums may not equal total due to rounding since individual table values were derived by allocating percentages of the totals to each zone. Values in long tons.

size of 4,023 long tons for impact casualties, 11,500 long tons for nonimpact casualties and the appropriate spill rates from tables V-9 and V-10. It can be seen that most of the predicted spillage occurs in the straits and channels. Further, most of the predicted spillage is due to impact casualties (more than double that for nonimpact casualties for LOOP and about double for SEADOCK).

In section IV-C a linear regression relationship was derived for the expected amount of oil spill as a function of volume throughput. Evaluating this relationship for the LOOP and SEADOCK throughput values over 30 years yields the following results for the expected spillage:

LOOP	62,900 long tons
SEADOCK	95,300 long tons

These values are comparable to the results from the risk analysis given in tables V-14 and V-15.

LOOP	53,700 long tons
SEADOCK	86,500 long tons

The comparison is interesting because the two spill estimates derive from two different data sources; the regression curve is based on PIRS data while the risk analysis is based upon the Tanker Casualty File Data.

2. Probability of a Spill Greater Than A Specified Size

Very large oil spills generally attract much more attention than do several small spills resulting in the same total amount spilled. This subsection addresses the problem of estimating the probability of at least one spill of a specified size or greater occurring in the Gulf as a result of the deepwater port operations.

The probability of at least one spill of size greater than s is given by:

$$P(s) = 1 - \sum_{n=o}^{\infty} p(n) \left(F(s)\right)^n \qquad (9)$$

where:

$p(n)$ = probability of n spills (probability density function for spill frequency)

$F(s)$ = probability a spill has size less than s (cumulative distribution function for spill size)

Beyer and Painter[1] used this formulation with a Poisson distribution for p(n). The equation using the negative binomial for p(n), derived in Appendix B, is:

$$P(s) = 1 - \{1 + \frac{t}{T}(1 - F(s))\}^{-N} \tag{10}$$

where:

T = past exposure (tanker days or port calls)

N = past number of spills

t = future exposure

The P(s) formulation was used to estimate the probability of spills of size at least as large as certain major historical spills. Table V-16 lists seven of the major oil spills that have occurred from impact accidents over the last 12 years. The largest was the Amoco Cadiz, which grounded off the coast of France in March 1978. The spill was estimated at 220,000 long tons. The largest spill size recorded in the Tanker Casualty File for the 1969-1973 period is the Sea Star, a Korean tanker that sank as a result of a collision in the West Indian Ocean in December 1972. These spill sizes are used in the P(s) evaluation: 220,000 long tons, corresponding to the Amoco Cadiz spill, and 109,500 tons, corresponding to the Torrey Canyon spill.

Evaluation of F(s) in Equation 10 for large spill sizes involves estimation of the extreme righthand tails of the log normal spill size distributions. Because this region represents an extrapolation of the spill data, the fit in the tails is not necessarily reliable. For this reason a lower bound on the probability value in the tails was used, based upon the mean, mode, and standard deviation of the data. The method, a variation of the Chebyshev inequality, is discussed in appendix C. The lower bound on F(s) translates into an upper bound on P(s), which is a monotonically decreasing function of F(s).

The results are summarized in table V-17. Thus, it is estimated that there is a 6 percent probability of a spill at least as large as the Amoco Cadiz spill during the 30-year period. The recurrence interval (average time between spills) for spills of that size is approximately 490 years. There is a 25 percent probability of a spill at least as large as the Torrey Canyon spill, which implies a recurrence interval of 120 years. Note that these probabilities represent upper bounds based upon the data and assumptions of the study.

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1. A. H. Beyer and L. J. Painter, "Estimating the Potential for Future Oil Spills from Tankers, Offshore Development and Onshore Pipelines," 1977 Oil Spill Conference, New Orleans, Louisiana, March 8-10, 1977.

Table V-16. Major Tanker Casualty Oil Spills in the World (1967-1978)

Year	Name of Vessel	Location	Type of Accident	Amount of Oil Spilled (in Long Tons)
1978	Amoco Cadiz	NW Coast of France	Grounding	220,000
1972	Sea Star	West Indian Ocean	Collision	120,300*
1967	Torrey Canyon	SW Coast of England	Grounding	109,500
1974	Metula	Straits of Magellan	Grounding	47,600
1974	Transhuron	SW Coast of India	Grounding	26,600
1976	Argo Merchant	SE Nantucket	Grounding	23,200

*Included in the Tanker Casualty File data base 1969-1973.

Table V-17. Probability of Large Spill Sizes During Deepwater Port Operations (30-Year Period)

Casualty Type	Amoco Cadiz (s = 220,000 LT) F*(s)	P(s) LOOP	P(s) SEADOCK	P(s) TOTAL	Torrey Canyon (s = 109,500 LT) F*(s)	P(s) LOOP	P(s) SEADOCK	P(s) TOTAL
Impact	.9979	.020	.029	.049	.9912	.081	.118	.199
Non-Impact	.9969	.004	.008	.012	.9858	.018	.035	.053
		.024	.037	.061		.099	.153	.252

F*(s) = Lower bound for the probability of a spill size no greater than s, given a spill has occurred.

P(s) = Probability of at least one spill of size greater than s during the 30-year period.

Table IV-18 through V-21 present the P(s) values by time period and transit zone for LOOP and SEADOCK. The largest probability value by zone is for the straits and channels, which is approximately double the value for the safety zone. The safety zone value, in turn, is about double that of the traffic separation scheme and safety fairway and not quite double that of the Gulf open sea.

As noted previously, the spill size distributions are highly skewed to the left, implying that the vast majority of spills are quite small. Based upon the fitted log normal distributions for spill size, it is predicted that 45 percent of the spills that occur will be less than 500 long tons and 80 percent will be less than 5,000 long tons.

Table V-18. Probability of at Least One Spill Greater Than That of the Amoco Cadiz by Time Period and Zone for LOOP

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	.0011	.0001	.0003	.0005	.0020
	Non-Impact	.0000	.0002	.0000	.0001	.0004
	Total	.0011	.0003	.0003	.0006	.0024
1985-1989	Impact	.0015	.0002	.0004	.0007	.0028
	Non-Impact	.0000	.0004	.0001	.0001	.0006
	Total	.0015	.0006	.0005	.0008	.0034
1990-1994	Impact	.0018	.0002	.0005	.0009	.0033
	Non-Impact	.0000	.0004	.0001	.0002	.0007
	Total	.0018	.0006	.0006	.0011	.0040
1995-1999	Impact	.0021	.0002	.0005	.0010	.0038
	Non-Impact	.0000	.0005	.0001	.0002	.0008
	Total	.0021	.0007	.0006	.0012	.0046
2000-2004	Impact	.0022	.0002	.0006	.0011	.0041
	Non-Impact	.0000	.0005	.0001	.0002	.0008
	Total	.0022	.0007	.0007	.0013	.0049
2005-2009	Impact	.0022	.0002	.0006	.0011	.0041
	Non-Impact	.0000	.0005	.0001	.0002	.0008
	Total	.0022	.0007	.0007	.0013	.0049
1980-2009	Impact	.0109	.0011	.0028	.0052	.0200
	Non-Impact	.0002	.0024	.0004	.0010	.0040
	Total	.0111	.0035	.0032	.0062	.0240

Note: Sums may not equal totals due to rounding since individual table values were derived by allocating percentages of the totals to each zone. Amoco Cadiz spill = 220,000 long tons.

Table V-19. Probability of at Least One Spill Greater Than That of the Torrey Canyon by Time Period and Zone for LOOP

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	.0045	.0005	.0012	.0021	.0083
	Non-Impact	.0001	.0011	.0002	.0004	.0018
	Total	.0046	.0016	.0014	.0025	.0101
1985-1989	Impact	.0061	.0006	.0016	.0029	.0112
	Non-Impact	.0001	.0015	.0002	.0006	.0025
	Total	.0062	.0021	.0018	.0035	.0137
1990-1994	Impact	.0073	.0008	.0019	.0035	.0134
	Non-Impact	.0002	.0018	.0003	.0007	.0030
	Total	.0075	.0026	.0022	.0042	.0164
1995-1999	Impact	.0084	.0009	.0021	.0040	.0153
	Non-Impact	.0002	.0021	.0003	.0008	.0034
	Total	.0086	.0030	.0024	.0048	.0187
2000-2004	Impact	.0090	.0009	.0023	.0042	.0164
	Non-Impact	.0002	.0022	.0003	.0009	.0037
	Total	.0092	.0031	.0026	.0051	.0201
2005-2009	Impact	.0090	.0009	.0023	.042	.0164
	Non-Impact	.0002	.0022	.0003	.0009	.0037
	Total	.0092	.0031	.0026	.0051	.0201
1980-2009	Impact	.0442	.0045	.0113	.0210	.081
	Non-Impact	.0010	.0109	.0016	.0044	.018
	Total	.0452	.0154	.0129	.0254	.099

Note: Sums may not equal totals due to rounding since individual table values were derived by allocating percentages of the totals to each zone. Torrey Canyon spill = 109,500 long tons.

Table V-20. Probability of at Least One Spill Greater Than That of the Amoco Cadiz by Time Period and Zone for SEADOCK

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	.0019	.0002	.0005	.0009	.0034
	Non-Impact	.0000	.0006	.0001	.0002	.0009
	Total	.0019	.0008	.0006	.0011	.0043
1985-1989	Impact	.0025	.0003	.0006	.0012	.0045
	Non-Impact	.0001	.0008	.0001	.0002	.0012
	Total	.0026	.0011	.0007	.0014	.0057
1990-1994	Impact	.0028	.0003	.0007	.0013	.0052
	Non-Impact	.0001	.0010	.0001	.0003	.0014
	Total	.0029	.0013	.0008	.0016	.0066
1995-1999	Impact	.0028	.0003	.0007	.0013	.0052
	Non-Impact	.0001	.0010	.0001	.0003	.0014
	Total	.0029	.0013	.0008	.0016	.0066
2000-2004	Impact	.0029	.0003	.0007	.0014	.0053
	Non-Impact	.0001	.0010	.0001	.0003	.0015
	Total	.0030	.0013	.0008	.0017	.0068
2005-2009	Impact	.0030	.0003	.0008	.0014	.0055
	Non-Impact	.0001	.0010	.0001	.0003	.0015
	Total	.0031	.0013	.0009	.0017	.0070
1980-2009	Impact	.0158	.0016	.0040	.0075	.029
	Non-Impact	.0004	.0055	.0005	.0015	.008
	Total	.0162	.0071	.0045	.0090	.037

Note: Sums may not equal totals due to rounding since individual table values were derived by allocating percentages of the totals to each zone. Amoco Cadiz spill = 220,000 long tons.

Table V-21. Probability of at Least One Spill Greater Than That of the Torrey Canyon by Time Period and Zone for SEADOCK

Period	Casualty Type	Straits & Channels	Gulf Open Sea	Fairway & TSS	Safety Zone	Total
1980-1984	Impact	.0075	.0008	.0019	.0036	.0138
	Non-Impact	.0002	.0028	.0003	.0008	.0041
	Total	.0077	.0036	.0022	.0044	.0179
1985-1989	Impact	.0100	.0010	.0025	.0047	.0183
	Non-Impact	.0003	.0037	.0004	.0010	.0054
	Total	.0103	.0047	.0029	.0057	.0237
1990-1994	Impact	.0115	.0012	.0029	.0054	.0210
	Non-Impact	.0003	.0043	.0004	.0012	.0062
	Total	.0118	.0055	.0033	.0066	.0272
1995-1999	Impact	.0115	.0012	.0029	.0054	.0210
	Non-Impact	.0003	.0043	.0004	.0012	.0062
	Total	.0118	.0055	.0033	.0066	.0272
2000-2004	Impact	.0117	.0012	.0030	.0056	.0215
	Non-Impact	.0003	.0044	.0004	.0012	.0064
	Total	.0120	.0056	.0034	.0068	.0279
2005-2009	Impact	.0122	.0013	.0031	.0058	.0224
	Non-Impact	.0004	.0046	.0004	.0013	.0067
	Total	.0126	.0059	.0035	.0071	.0291
1980-2009	Impact	.0644	.0066	.0164	.0306	.118
	Non-Impact	.0019	.0241	.0023	.0067	.035
	Total	.0663	.0307	.0187	.0373	.153

Note: Sums may not equal totals due to rounding since individual table values were derived by allocating percentages of the totals to each zone. Torrey Canyon spill = 109,500 long tons.

VI. HAZARD IDENTIFICATION AND RANKING

Potential hazards to tankers transiting the Gulf of Mexico to and from the deepwater ports were assessed independently by several methods. First, a paper transit was performed using the most likely routes within the Gulf and potential hazards were identified along each segment of the routes. The hazards were then subjectively rated in order of potential danger.

Additional information on hazards was obtained from observations by study team members during an actual tanker transit of the Gulf and a visit to the Saudi Arabian deepwater port of Ras Tanura.

A detailed fault tree analysis was performed to study the relationships between the various causal factors for vessel accidents.

Historical casualty data from the Vessel Casualty Reporting System and the Tanker Casualty File were used to identify and rank hazards by transit zone. The information from the actual and paper transits was then used in adjusting these rankings to develop a final hazard ranking against which various mitigating measures can be assessed.

A. Hazard Identification

1. Paper Transit of Vessel Routes Into and Out of the Gulf of Mexico

a. General

Two deepwater ports are planned for construction off the Gulf Coast of the U.S.; the Louisiana Offshore Oil Port (LOOP), and the Texas Offshore Oil Terminal (which will be referred to by its former name of SEADOCK in this discussion since a successor name has not yet been given). As shown in figure VI-1, LOOP is located in the Gulf of Mexico about 30 miles west of the Southwest Pass Entrance to the Mississippi River, 13.5 miles off the Louisiana coast, and SEADOCK, also in the Gulf of Mexico, is located 20 miles from the Texas coast, about 26 miles south of Freeport. Each facility will have a pumping platform complex (PPC) in the open sea, surrounded by single point moorings. Entrance to and exit from these facilities by vessels will be via a 5 to 6 mile traffic separation scheme (TSS) 2 to 2.5 miles wide, oriented in a southeasterly direction from the PPC, and a 2-mile wide safety fairway oriented in a north-south direction, 63 miles long at LOOP and 58 miles long at SEADOCK. As can also be seen from figure VI-1, tankers entering the Gulf of Mexico bound for LOOP and SEADOCK, are limited to two basic routes, the Straits of Florida and the Yucatan Channel. The purpose of this discussion is to examine

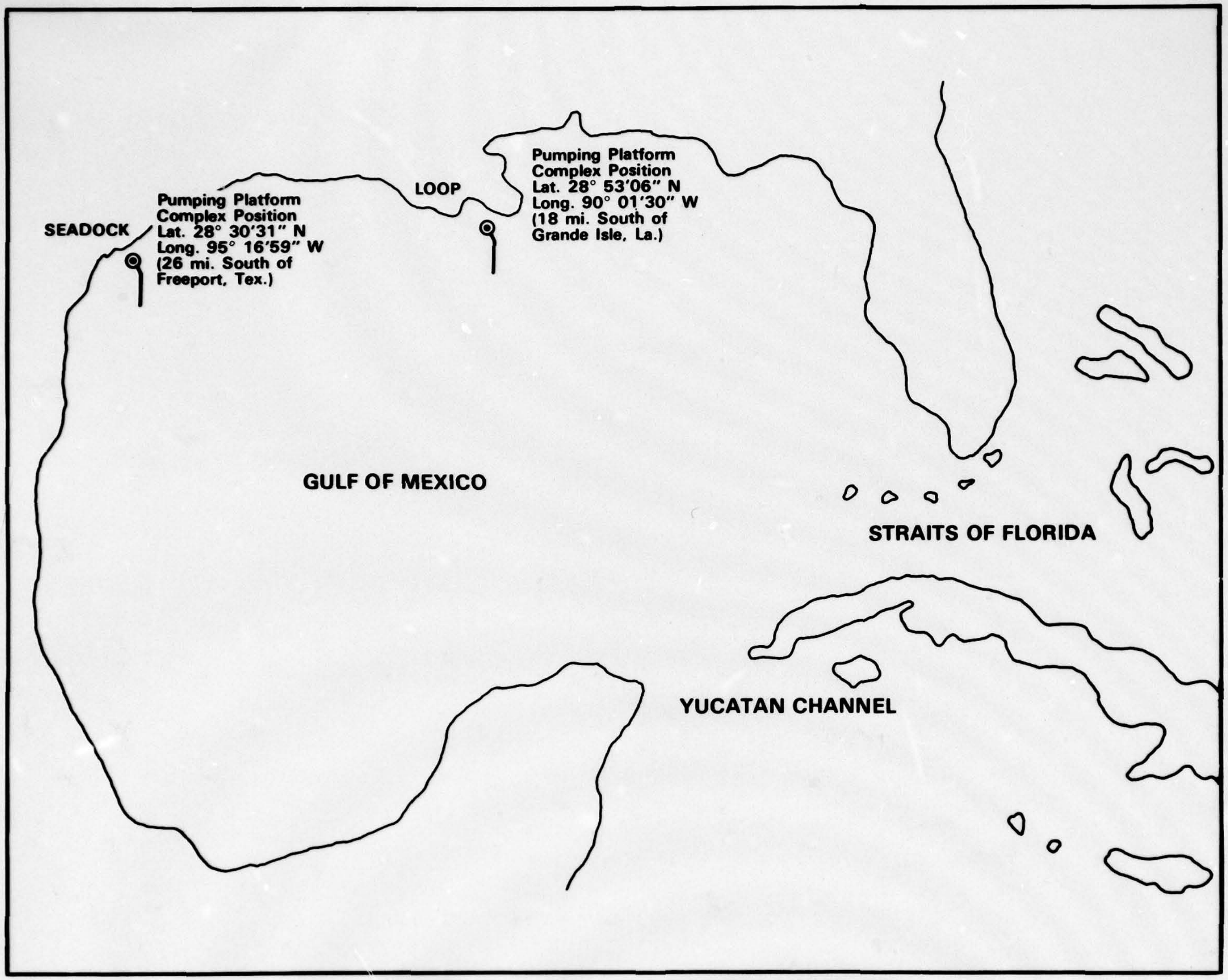

FIGURE VI-1. LOOP AND SEADOCK LOCATIONS

which routes lead to these two entrances, to ascertain the advantages and disadvantages of each, and attempt to assess the hazards which a vessel might expect to encounter.

The method used in this assessment might be equated to pre-voyage planning used by the master or navigator of a vessel whose destination is either LOOP or SEADOCK. Actual and up-to-date information for the entire route is, of course, absolutely necessary for successful planning and eventual execution of the voyage. This information is in the form of charts, sailing directions, coast pilots, tide and current tables, light lists, radio aids to navigation, weather broadcasts, hydrographic data, notices to mariners, technical services broadcasts, and even international or political considerations which might in some instances dictate the avoidance of certain routes. Obviously, planning an ocean voyage requires knowledge of origin as well as destination; origin will, in fact, dictate the route. Since origin must be determined by oil source, this must constitute the first step in examining routes into the Gulf of Mexico.

During their first year of operation, the crude oil throughput to LOOP and SEADOCK has been estimated to come from the following sources and in the following amounts:

Oil Source	LOOP[1]			SEADOCK[2]		
	MMBD	Millions of Long Tons/Year	%	MMBD	Millions of Long Tons/Year	%
Persian Gulf	.840	42	60	1.75	87.5	70
West Africa	.294	14.7	21	.70	35	28
North Africa	.182	9.1	13	.05	2.5	2
North Sea	.084	4.2	6	-	-	-
Total	1.40	70.0	100	2.5	125.0	100

It is estimated that the number of vessels which will carry this oil will be 326 vessels per year at LOOP and 569 vessels per year at SEADOCK. Vessel sizes are expected to range from 50,000 to 500,000 DWT.

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1. Conversation, Mr. James Brian, LOOP, May 2, 1978.
2. U.S. Coast Guard. Final Environmental Impact Statement. SEADOCK Deepwater Port License Application, Volume 3. Washington, D.C.: 1976, p. B-124.

Since the shortest routes from the Persian Gulf and North Africa to the Gulf of Mexico are via the Cape of Good Hope and the Straits of Gibraltar, respectively, and Lagos, Nigeria is the only oil port in West Africa, the origins of the oil routes to LOOP and SEADOCK can be established as:

- Cape of Good Hope
- Lagos, Nigeria
- The Straits of Gibraltar
- The North Sea

The widening and deepening of the Suez Canal, which is now underway and scheduled for completion by mid-1980, will accommodate fully loaded tankers of 150,000 DWT. Further enlargement is planned which will permit 260,000 DWT tankers to pass through fully loaded.[1] When this construction is completed, VLCCs coming from the Persian Gulf may, depending upon their size, have a choice of two routes to the Gulf of Mexico. The four origins listed above, therefore, will not change; the amount of vessel traffic on these routes may, however, vary. Voyage planning, therefore, can be limited to these four starting points, and it must then be determined which of the two entrances to the Gulf of Mexico provides the safest and shortest route. It must be kept in mind, however, that the shortest route may not always be the most desirable due to many factors such as adverse weather, unfavorable currents, and other hazards to navigation.

In the course of this discussion, it will be necessary to treat a wide range of routes into and out of the Gulf of Mexico, since such a discussion will have application to the desirability of these routes. The main concern, however, will be those routes which traverse some portion of the Straits of Florida since a concentration of oil tankers in this area poses a threat to the delicate marine ecology of the State of Florida. The Yucatan Channel, on the other hand, is wide, free of obstructions, has no U.S. littoral, and therefore is not an area of primary concern to the U.S. Coast Guard.[2] Since the routes within the Gulf of Mexico are common to all routes to LOOP and SEADOCK, they will be covered as a separate item and will not be repeated for each route.

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1. EXXON Corporation. "Skandia In Suez," Exxon Marine, Summer 1978, Volume 23, No. 2, pp. 28-33.
2. Meeting with Deepwater Ports Project Personnel, November 3, 1977.

b. Discussion of Routes

(1) Cape of Good Hope to Gulf of Mexico

There are three routes recommended from the Cape of Good Hope to the Gulf of Mexico:

Route No. 1 -- North of Barbados, via St. Lucia Channel, Mona Passage, north of Hispaniola, via the Old Bahama Channel, Nicholas Channel, and the Straits of Florida.[1]

Route No. 2 -- Galleon's Passage (between Trinidad and Tobago), thence great circle north of Jamaica and Cayman Brac, thence rhumb line to the Yucatan Channel.[2]

Route No. 3 -- Galleon's Passage, thence a great circle south of Jamaica, and a rhumb line to the Yucatan Channel.[3]

These routes are shown in figures VI-2 and VI-3.

Since they complement one another, the return routes from the Gulf of Mexico to the Cape of Good Hope are shown in figure VI-4. They will not be described or treated except to say they were chosen to avoid the west-setting Caribbean Current, and take advantage of the east-setting Florida Current.

Although Route No. 1 has the advantage of being the shortest route from the Cape of Good Hope to LOOP (see figure VI-5), it has serious disadvantages. The Old Bahama Channel is long and relatively narrow, its least width being about 10 miles. It is bounded on the north by the low-lying and submerged Great Bahama Bank, which is marked by very few aids to navigation, and on the south by the steep to, poorly lighted north coast of Cuba. The Old Bahama Channel is very deep, seldom less than 250 fathoms; however, the 100-fathom curve

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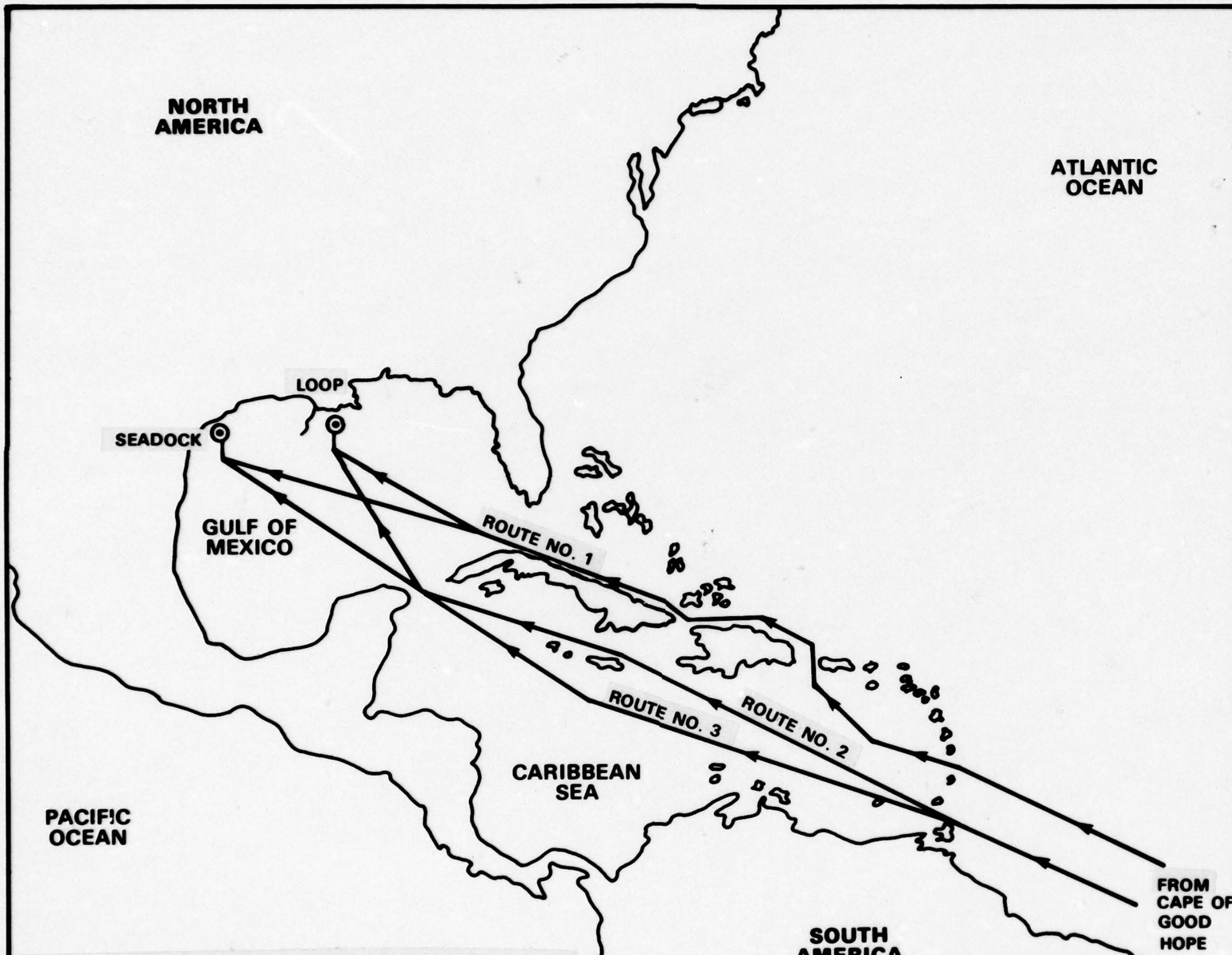
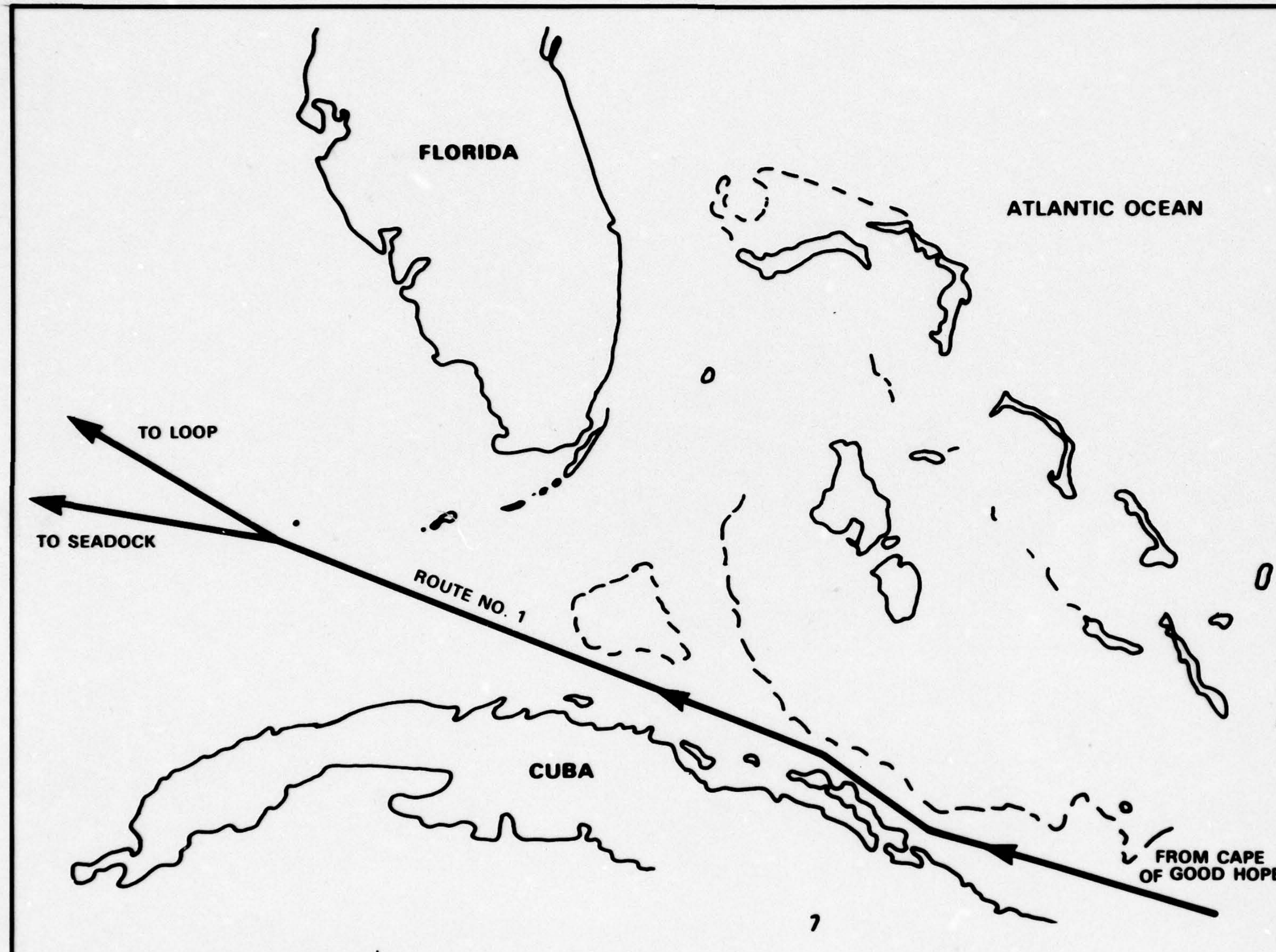
1. Defense Mapping Agency Hydrographic Center, Sailing Directions for Southwest Coast of Africa, Cape Palmas to Cape of Good Hope, Fifth Edition, 1969. (Revised Edition 1976), Publication 50. (Washington, D.C.: DMAHC, 1976), p. 72.
2. U.S. Naval Hydrographic Office, Sailing Directions for the East Coasts of Central America and Mexico, Fifth Edition, Publication 20 (formerly No. 130). (Washington, D.C.: USNHQ, 1952), p. 54. (Although p. III of the Preface to Publication 144 states that it replaces publication 20, the ocean routes do not appear in publication 144. Since these routes do not appear in any other volume of the DMAHC Sailing Directions, it is assumed that their omission was an oversight.)
3. Defense Mapping Agency Hydrographic Center, Sailing Directions for the Southeast Coast of Africa, Cape of Good Hope to Ras Hafun, Fifth Edition, 1968. (Revised Edition 1975), Publication 60. (Washington, D.C.: DMAHC, 1975), p. 26.



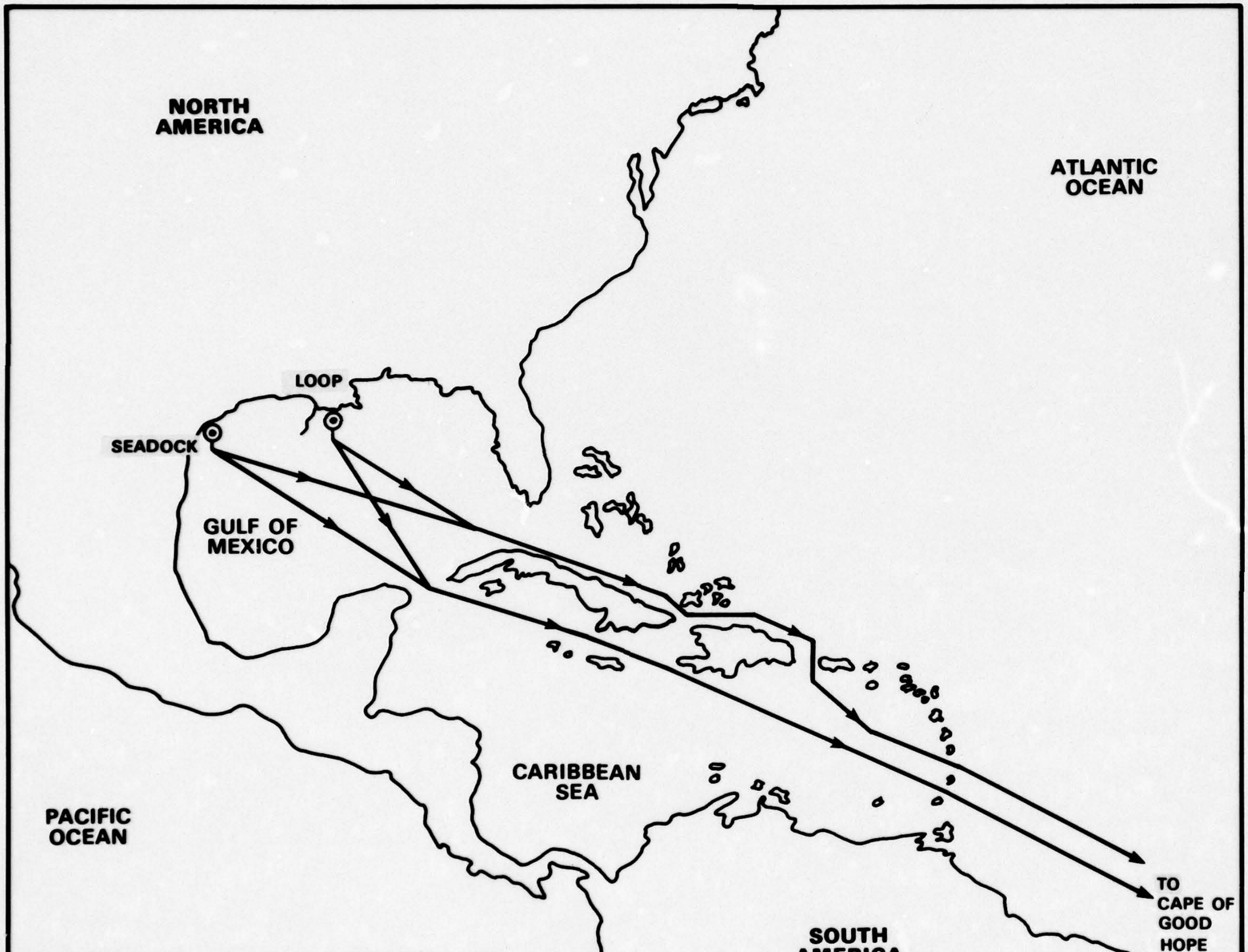
SOURCE: *Sailing Directions*, Pubs. 20, 50, and 60. DMAHC, Washington, D.C.

FIGURE VI-2. RECOMMENDED ROUTES CAPE OF GOOD HOPE TO LOOP AND SEADOCK



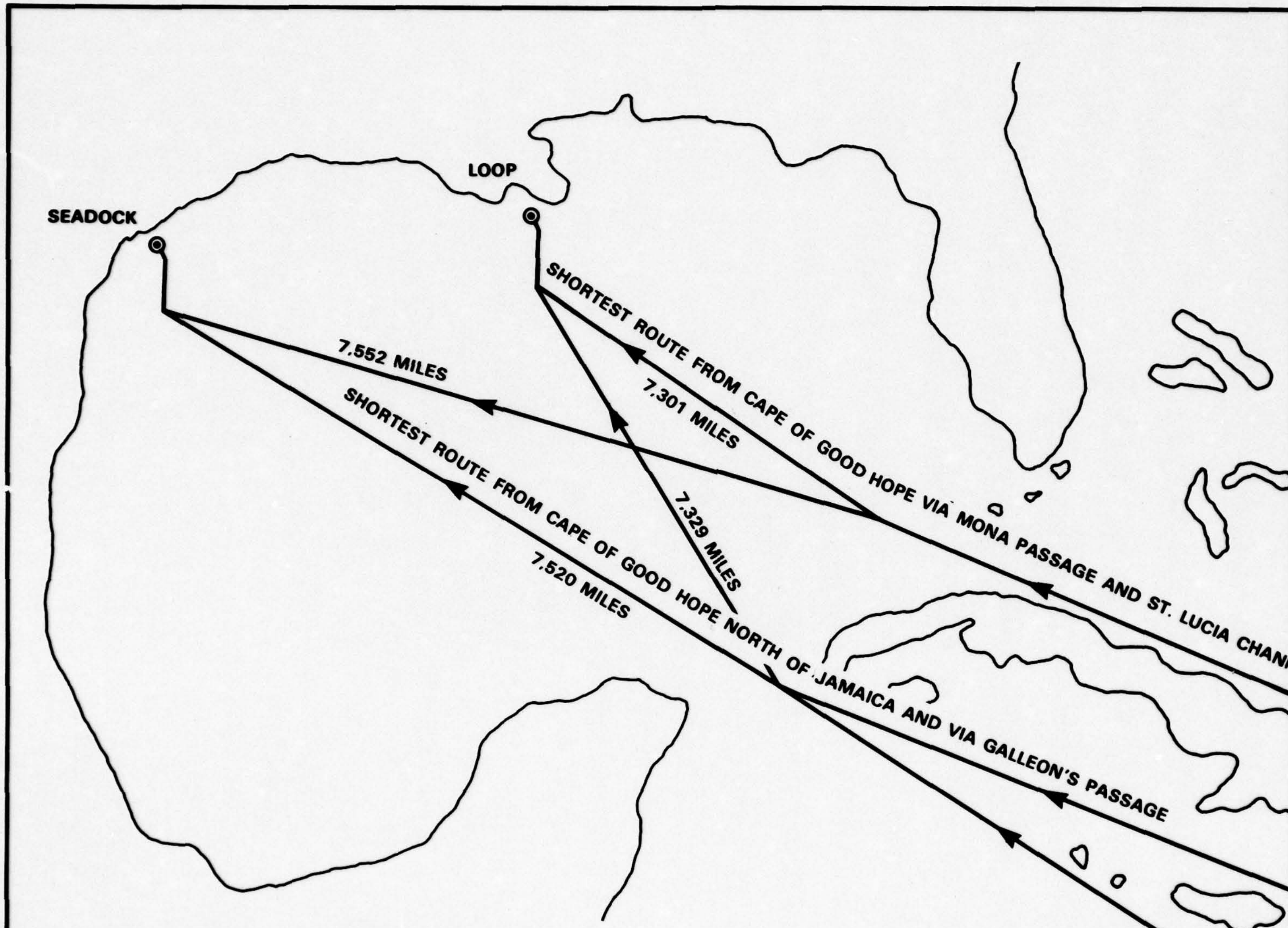
Source: *Sailing Directions, S. W. Coast of Africa*, 5th Ed., Pub. 50.
DMAHC, Washington, D.C., 1976.

FIGURE VI-3. RECOMMENDED ROUTE FROM CAPE OF GOOD HOPE VIA ST. LUCIA CHANNEL AND MONA PASSAGE



SOURCE: *Sailing Directions*, Pubs. 20, 50, and 60. DMAHC, Washington, D.C.

FIGURE VI-4. RECOMMENDED ROUTES FROM LOOP AND SEADOCK TO CAPE OF GOOD HOPE



SOURCE: *Distances Between Ports,* Pub. 151. Defense Mapping Agency Hydrographic Center, Washington, D.C., 1976.

FIGURE VI-5. SHORTEST ROUTES FROM CAPE OF GOOD HOPE TO LOOP AND SEADOCK

is so close to the reef line on the north, and the coast line on the south, that soundings give little, if any any, warning of shoal water. Furthermore, numerous reports indicate the unreliability of aids to navigation along the Cuban Coast.[1] In inclement weather all of these factors are decided disadvantages.[2] During the hurricane season, for example, the Old Bahama Channel route restricts a vessel's ability to make storm evasion maneuvers. In addition, there have been instances of Cuban Navy interference with transiting vessels. Finally, one of the most important disadvantages of this route is the fact that it does not utilize any favorable currents, such as the Caribbean Current and, in fact, the 100-mile portion of the Straits of Florida traversed on this route is actually in opposition to the Florida Current.

Should a vessel choose to use Route No. 1, it would cross the main axis of the Florida Current just west of Key West enroute to the main traffic junction point southwest of Dry Tortugas. Since eastbound vessels would be seeking to take full advantage of the Florida Current, a large amount of opposing vessel traffic would be encountered in this leg of the route. Cay Sal Bank on the northern side of Nicholas Channel would be an additional hazard, as would the Florida reefs from Key West to Dry Tortugas. Some recreational and commercial fishing also takes place on this portion of the route.

Route No. 2 north of Jamaica is geographically the shortest route from the Cape of Good Hope to SEADOCK (see figure VI-5), it does not, however, take the best advantage of the Caribbean Current.

Route No. 3, which goes south of Jamaica, takes advantage of the Caribbean Current over almost its entire transit of the Caribbean Sea. The Caribbean Current, although seldom mentioned in the literature, is among the most persistent and well-defined of the major ocean currents. It sets westward through the Caribbean Sea throughout the year from the Windward Islands to the Yucatan Channel between 65 and 75 percent of the time at a mean speed of 0.9 knots, and, at times, a maximum speed of 3.5 knots. The flow in the prevailing direction is very consistent since it is located in a trade wind area and has little variation between seasons.[3] Since the Caribbean portion of this route is approx-

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1. Defense Mapping Agency Hydrographic Center. Sailing Directions (En Route) for the Caribbean Sea, First Edition, Publication 144. Washington, D.C.: DMAHC, 1976, p. 37.
2. Ocean Passages for the World. Third Edition. Somerset, England: Hydrographic Department, 1973, pg. 57.
3. U.S. Naval Oceanographic Office. Major Currents in the North and South Atlantic Oceans Between 64°N and 60°S. Washington, D.C.: U.S.N.O.O., 1967, p. 37.

imately 1,500 miles, a 15-knot vessel could gain reliably about a 90-mile advantage with the possibility of over 300 miles at times. Clearly, Route No. 3 offers the most advantages to a vessel travelling from the Cape of Good Hope to both LOOP and SEADOCK; therefore, it seems reasonable to suppose that most vessels coming from the Persian Gulf will use it.

Lagos, Nigeria to Gulf of Mexico

There are two routes recommended from Lagos, Nigeria to the Gulf of Mexico:

Route No. 1 - A great circle track from south of Cape Palmas, Africa to north of Sombrero, which marks the northern entrance to Anegada Passage in the Leeward Islands, thence by rhumb line north of Hispaniola, thence Old Bahama and Nicholas Channels to the Straits of Florida. (See figure VI-6 for the western portion of the route.)

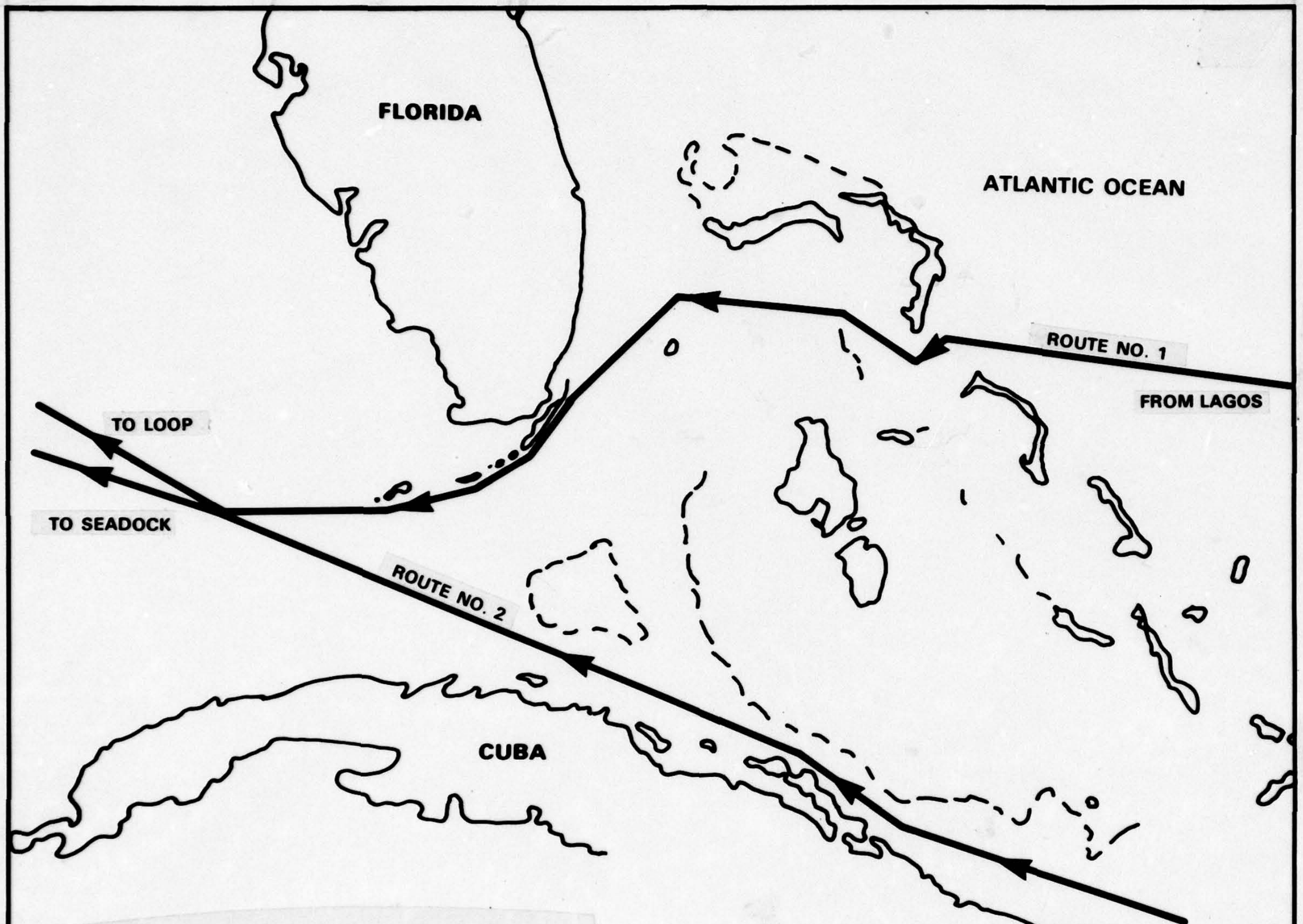
Route No. 2 - A great circle track from south of Cape Palmas, Africa to Hole-in-the-Wall at the eastern entrance to the Northeast Providence Channel, thence Northwest Providence Channel to north of Great Isaac, thence southwest across the Straits of Florida to a point about 1 mile east of Fowey Rocks, thence follow the Florida Reefs at a distance of 1.5 to 2 miles to Dry Tortugas. (See figure VI-6.)

Since they complement one another, the return routes from the Gulf of Mexico to Lagos, Nigeria are shown in figure VI-7. They will not be described or treated except to say that they were chosen to take maximum advantage of the east-setting Florida Current.

Route No. 1 is not only longer than No. 2 (5,242 miles versus 5,225 miles), but also has the severe disadvantages of the Old Bahama Channel passage which were previously discussed. In addition to this, the landfall in the Sombrero area of Anegada Passage is one of small, low-lying islands and reefs which are difficult to distinguish in inclement weather. Its single advantage is its shorter distance of travel against the Florida Current than Route No. 2.

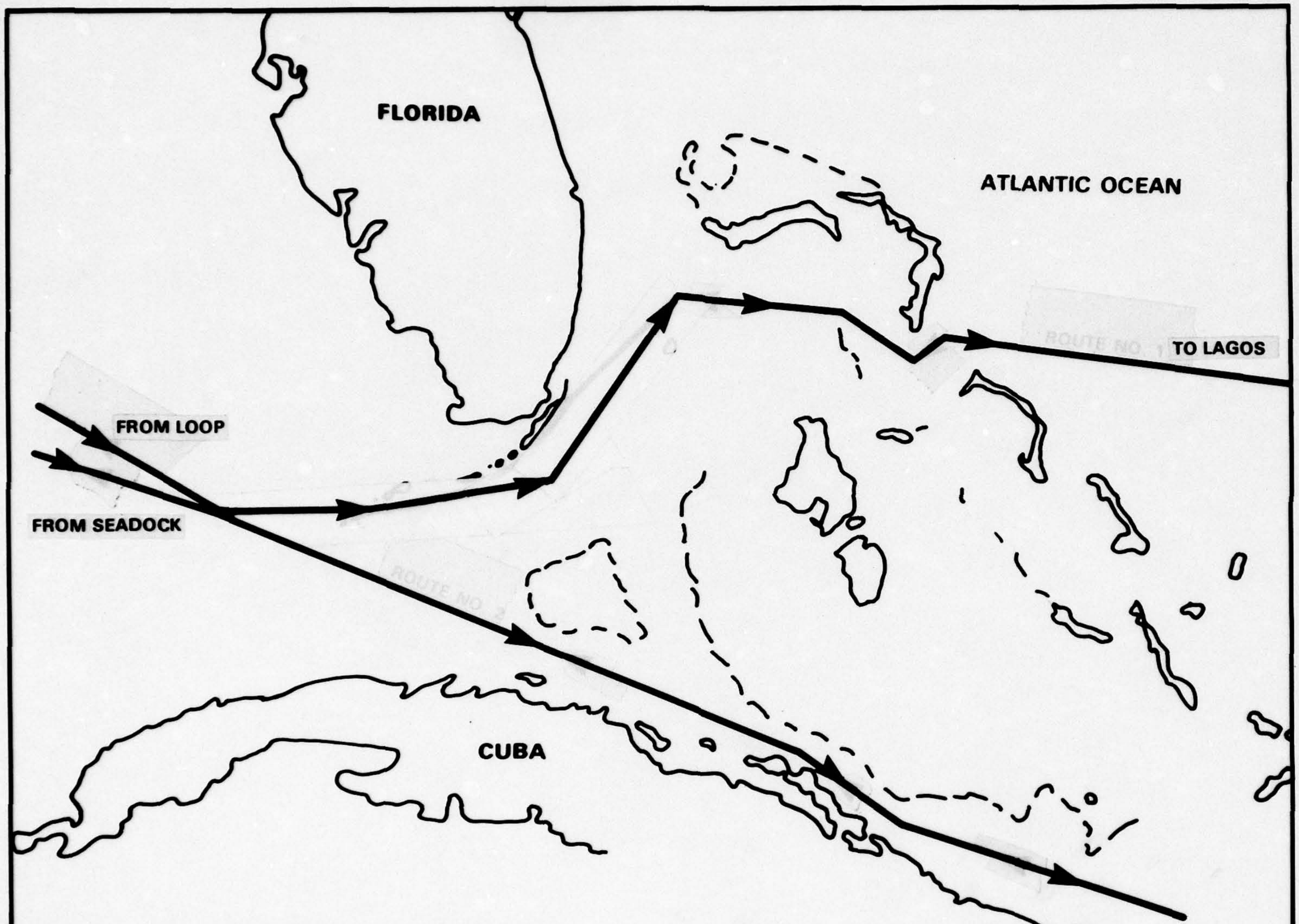
Route No. 2 is shorter than Route No. 1 and has the added advantages of better aids to navigation, a wider, deeper channel free of obstructions, and large, well-defined land masses more suitable for a landfall after a long ocean voyage.

Since the hazards of the Straits of Florida portion of Route No. 1 have been previously discussed, they will not be repeated. The principal hazards of Route No. 2 are: grounding on Great Abaco Island and Eleuthera



SOURCE: *Sailing Directions, S. W. Coast of Africa*, 5th Ed., Pub. 50. DMAHC, Washington, D.C., 1976.

FIGURE VI-6. RECOMMENDED ROUTES FROM LAGOS, NIGERIA TO LOOP AND SEADOCK



Source: *Sailing Directions, S. W. Coast of Africa*, 5th Ed., Pub. 50.
DMAHC, Washington, D.C., 1976.

FIGURE VI-7. RECOMMENDED ROUTES TO LAGOS, NIGERIA FROM LOOP AND SEADOCK

Island, which mark the eastern entrance to Northeast Providence Channel; grounding on the Berry Islands just inside the entrance on the south side of Northwest Providence Channel; grounding on Grand Bahama Island on the north side of Northwest Providence Channel and Great Bahama Bank on the south side; meeting and overtaking vessels in both channels, since this is a major shipping route; meeting vessels which are headed north taking advantage of the main axis of the Florida Current while crossing the Straits of Florida from Great Isaac at the west entrance of Northwest Providence Channel to Fowey Rocks; meeting southbound vessels hugging the Florida coast at Fowey Rocks; numerous recreational boats in the vicinity of Fowey Rocks, which is close to Miami, and an area of excellent deep sea fishing; grounding on the Florida reefs from this point to Dry Tortugas; encountering pleasure boats and commercial fishermen along the entire Florida reef area; overtaking other vessels and being overtaken; and encountering low visibility in rain squalls which are common to this area during most of the year. Between Fowey Rocks and Key West the Florida reefs are well marked for both day and night passage in clear weather. Frequent position fixing and depth sounding is necessary, however, over the entire route. The 50-fathom curve is from 2 to 4 miles from the Florida reefs except near Fowey Rocks where the 100-fathom curve is about 2 miles outside the reef. Extra care should be used between the Elbow and Molasses Reef in which vicinity a number of vessels have been lost. An extremely variable current against the vessel off Carysport Reef makes it important to fix the vessel's position at this point to pass well clear of the Elbow. In this area, also, from just north of Carysford Reef to Molasses Reef and extending up to 3 miles offshore of the reef line is Key Largo Coral Reef Marine Sanctuary, which is a protected area designated by the Secretary of Commerce as authorized by Section 302 of the Marine Protection, Research and Sanctuaries Act of 1972 (PL 92-532, 86 Stat. 1052). Although this designation apparently does not preclude vessel transit, it is an area of special ecological concern and, together with John Pennekamp State Park, serves as a major tourist attraction.

Just west of Key West Main Ship Channel there is a large U.S. Naval Operational Training Area which extends to approximately 10 miles west of Dry Tortugas and south to within 20 miles of the northern coast of Cuba. Although watercraft are not ordinarily excluded from transiting this area, 33 CFR 204.95 does provide for exclusion under certain conditions which involve hazards to watercraft such as bombing, strafing, and similar operations. These hazardous

operations are not conducted by the U.S. Navy without first ascertaining that the zone of operation is clear. Vessels in the area will be warned to leave. Even when such hazardous operations are not being conducted, U.S. Naval vessels, including submarines, can be expected to be performing various operations in this area, and transiting vessels should be alert to these maneuvers. In addition, the area south and west of Dry Tortugas is the junction point for routes heading into and out of the Gulf of Mexico, therefore, vessel traffic can be expected to converge on this area.

(3) Straits of Gibraltar to Gulf of Mexico

There is one recommended route from the Straits of Gibraltar (North Africa) to the Gulf of Mexico; that is, great circle from latitude 36°N, longitude 35°W to Hole-in-the-Wall at the eastern entrance to Northeast Providence Channel, thence as previously described under Route No. 2 from Lagos, Nigeria to the Gulf of Mexico entrance of the Straits of Florida.[1] (See figure VI-8.) The hazards over that route are likewise as previously discussed.

Since they complement one another, the return route from the Gulf of Mexico to the Straits of Gibraltar is shown in figure VI-9. This return route will not be described or treated except to say that it was chosen to take maximum advantage of the east and north set of the Florida Current.

(4) North Sea to the Gulf of Mexico

There are three recommended routes from the North Sea to the Gulf of Mexico:

Route No. 1 - From position latitude 43°N, longitude 50°W by great circle to a position about 10 miles northwest of Mantanilla Shoal, thence a southwesterly course to 1 mile east of Fowey Rocks, thence follow the Florida reefs at a distance to seaward of 1.5 to 2 miles to southwestward of Dry Tortugas. (See route "C" in figure VI-10.)[2]

Route No. 2 - Proceed as direct as safe navigation permits to position latitude 38°08'N, longitude 75°-15'W, off Diamond Shoal Light, thence rhumb lines through the following positions:

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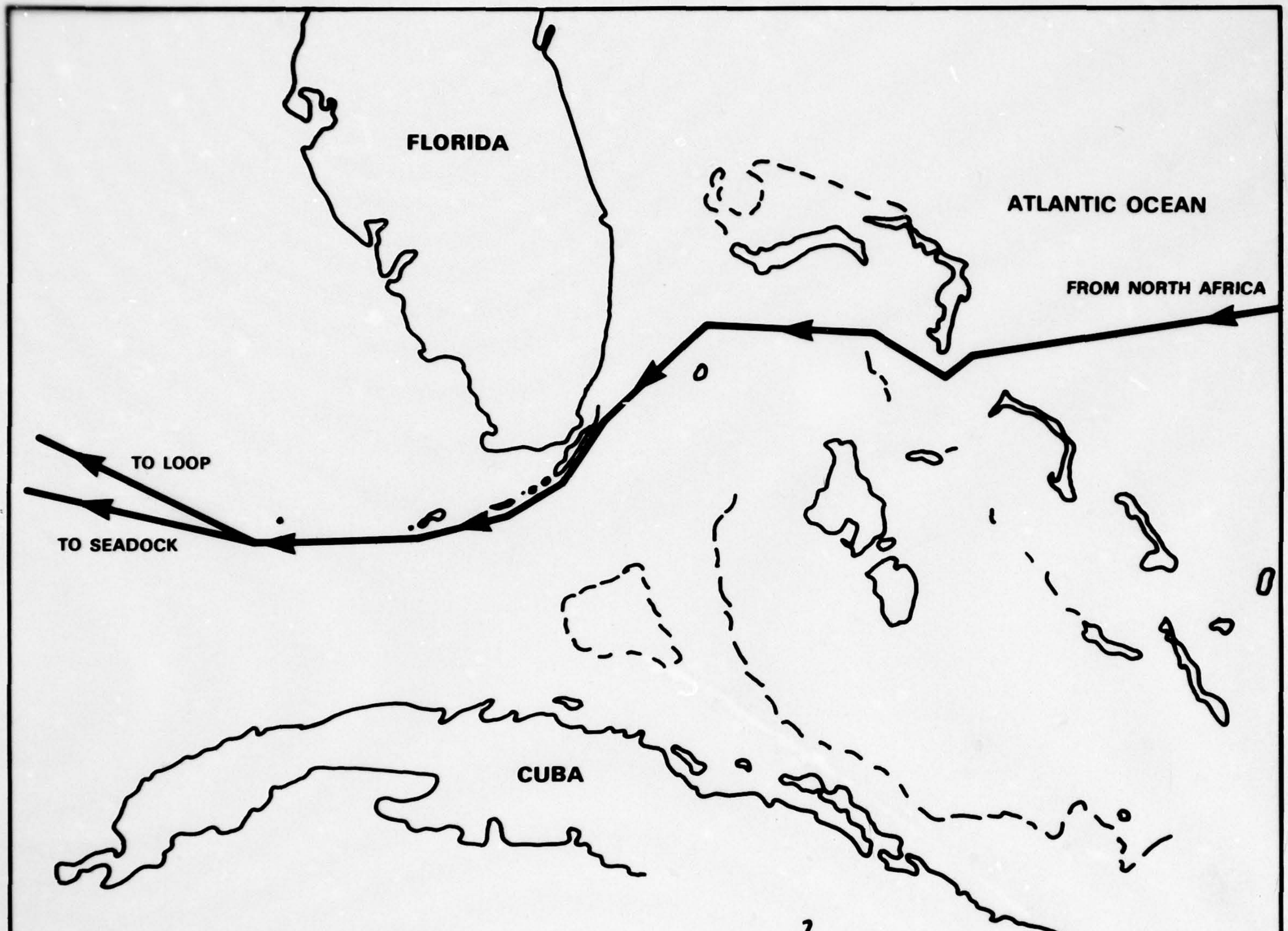
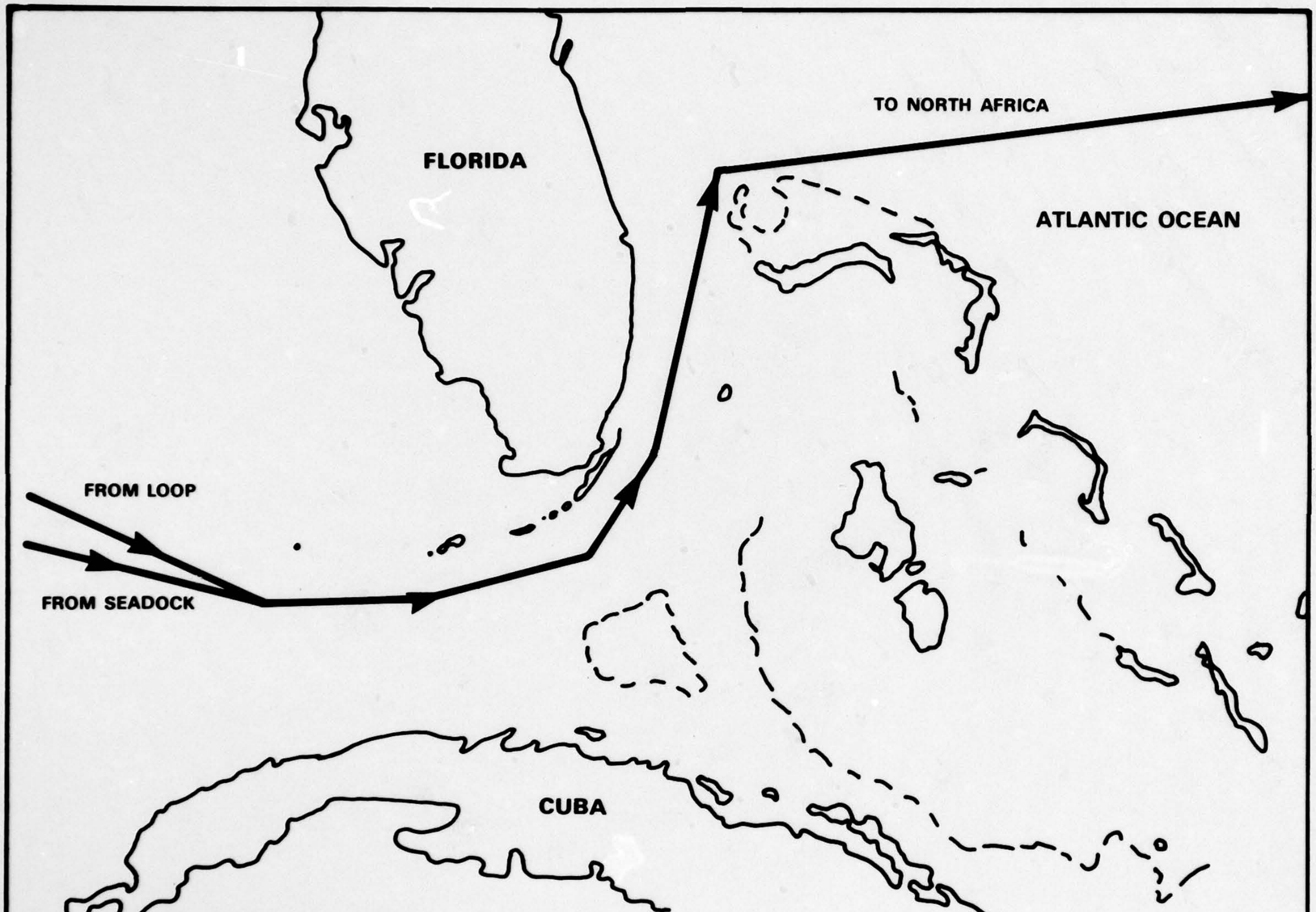
1. U.S. Navy Hydrographic Office. Sailing Directions for the East Costs of Central Ameica and Mexico. Fifth Edition. Publication 20 (Formerly Publication 130). Washington, D.C.: USNHO, 1952, p. 53.
2. Defense Mapping Agency Hydrographic Center. Sailing Directions (Planning Guide) for the North Atlantic Ocean. First Edition, Publication 140. Washington, D.C.: DMAHC, 1976, p.348.



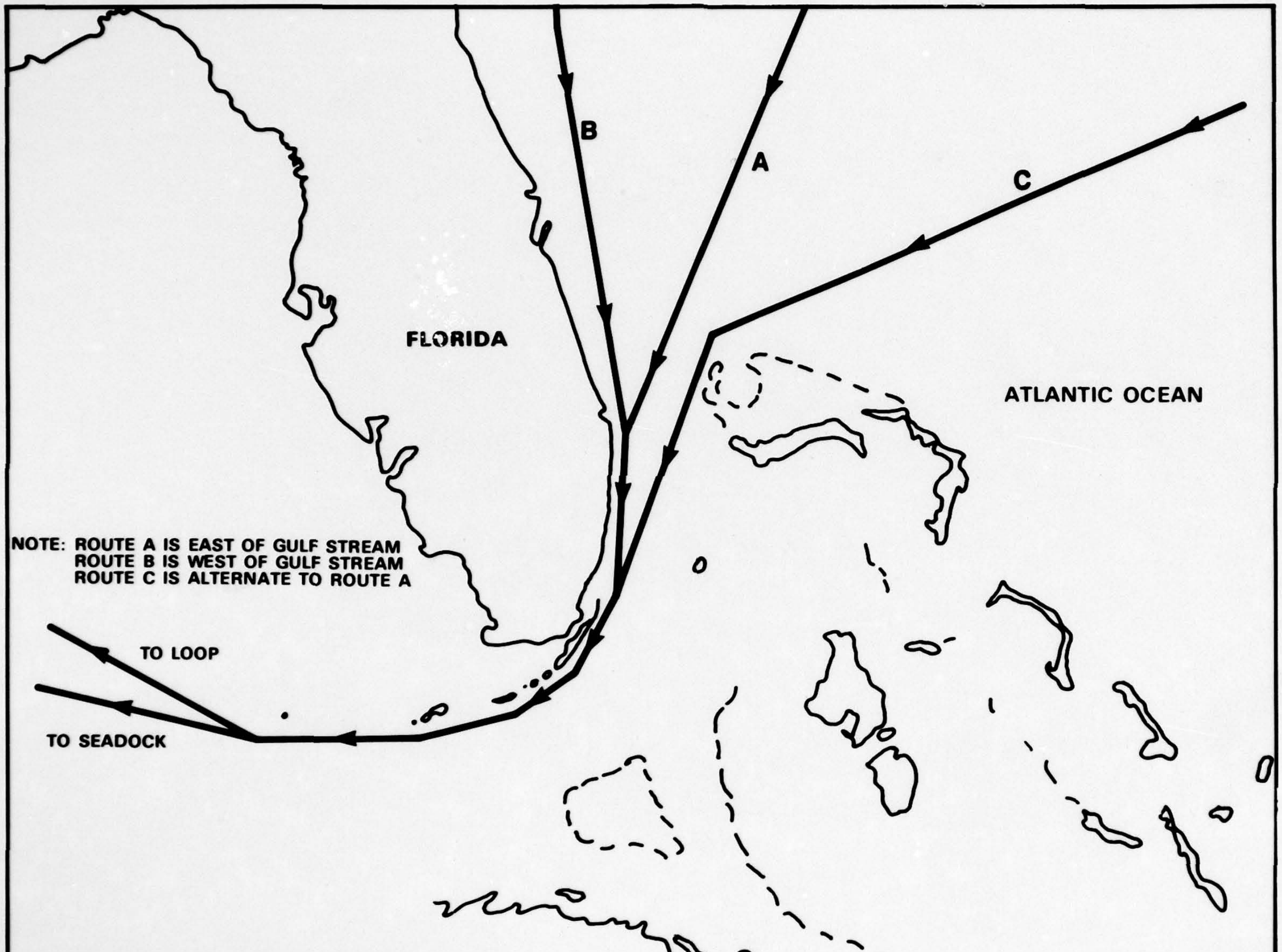
SOURCE: *Sailing Direction, E. Coasts Central America and Mexico,* 5th Ed. Pub. 20, U.S. Naval Oceanographic Officer, Washington, D.C., 1952.

FIGURE VI-8. RECOMMENDED ROUTE FROM NORTH AFRICA (STRAITS OF GIBRALTAR) TO LOOP AND SEADOCK



SOURCE: *Sailing Directions (Planning Guide), N. Atlantic Ocean*, 1st Ed., Pub. 140, DMAHC, Washington, D.C., 1976.

FIGURE VI-9. RECOMMENDED ROUTE FROM LOOP AND SEADOCK TO NORTH AFRICA (STRAITS OF GIBRALTAR)



SOURCE: *Sailing Directions (Planning Guide), N. Atlantic Ocean,* 1st Ed. Pub. 140. DMAHC, Washington, D.C., 1976.

FIGURE VI-10. RECOMMENDED ROUTES FROM NORTH SEA TO LOOP AND SEADOCK

33°-00'N, $75^{\circ}35$'W

28°-00'N, $79^{\circ}00$'W

26°-57'N, $80^{\circ}00$'W, off Jupiter Inlet Light.

This is known as the "outer route" and goes to the east of the Gulf Stream. (See route "A," figure VI-10.) Thence follow the coast of Florida and the Florida Keys as close as safe navigation permits to southwest of Dry Tortugas.[1]

Route No. 3 - Proceed as above for Route No. 2 off Diamond Shoal Light, thence rhumb lines through the following positions:

33°-27'N, $77^{\circ}32$'W off Frying Pan Shoals

$32^{\circ}00$'N, $80^{\circ}00$'W

$31^{\circ}00$'N, $80^{\circ}30$'W

$29^{\circ}30$'N, $80^{\circ}30$'W

$28^{\circ}39$'N, $80^{\circ}17$'W off Hetzel Shoal Lighted Whistle Buoy 8

$27^{\circ}24$'N, $80^{\circ}02$'W off wreck lighted buoy 12A

$26^{\circ}57$'N, $80^{\circ}00$W off Jupiter Inlet Light. (See Route "B," figure VI-9.) Thence follow the coast of Florida and the Florida Keys as close as safe navigation permits to Key West.[2]

Since they complement one another, the return routes from the Gulf of Mexico to the North Sea are shown in figure VI-11. These return routes will not be described or treated except to say that they were chosen to take maximum advantage of the Florida Current and the Gulf Stream.

Route No. 1 (route "C" on figure VI-10) makes a landfall on Mantanilla Shoal, which hazard should be given a wide berth. The northwestward extremity of the shoal is marked by a lighted whistle buoy, however, this buoy is not easy to sight. The bank in the area of the shoal is very hazardous, since the bottom is rocky and covered with dark marine growth, there is no change in water color, and there are no breakers. In addition, there is a strong current setting

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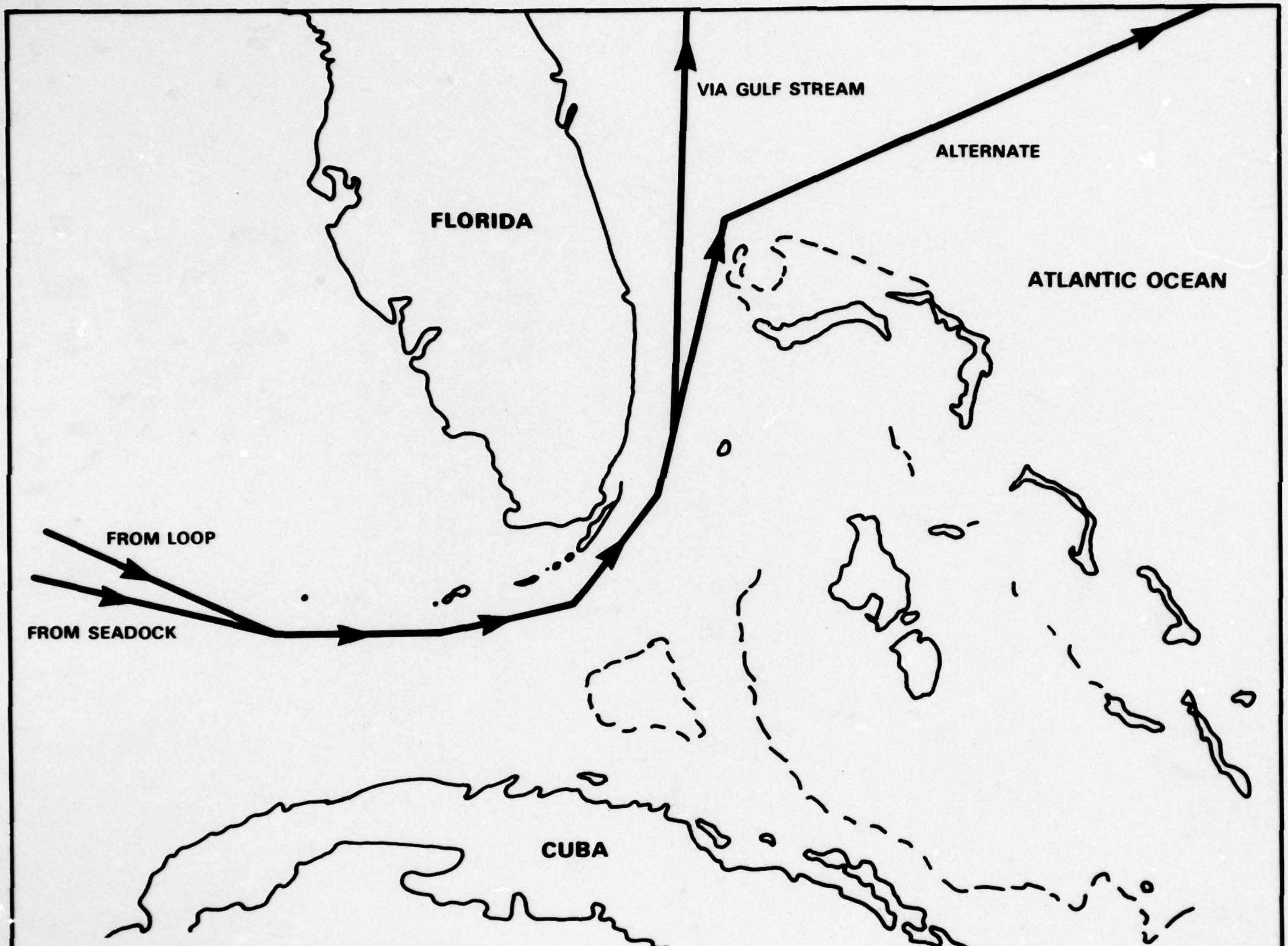
1. U.S. Department of Commerce. United States Coast Pilot 4 - Atlantic Coast, Cape Henry to Key West, Fifteenth Edition. Washington, D.C.: Superintendent of Documents, 1977, p. 63.
2. U.S. Coast Pilot 4, p. 63.



SOURCE: *Sailing Directions (Planning Guide), N. Atlantic Ocean,* 1st Ed., Pub. 140, DMAHC, Washington, D.C., 1976.

FIGURE VI-11. RECOMMENDED ROUTES FROM LOOP AND SEADOCK TO NORTH SEA

on the shoal near the edge of the bank. Overcast skies are not uncommon in this area, thus making celestial navigation somewhat unreliable, however, there is good Loran-C coverage, and until the end of 1980, good Loran-A coverage as well. Since Mantanilla Shoal is an important junction point for vessel traffic routes, vessels entering and leaving the Straits of Florida can be expected to be met in this area.

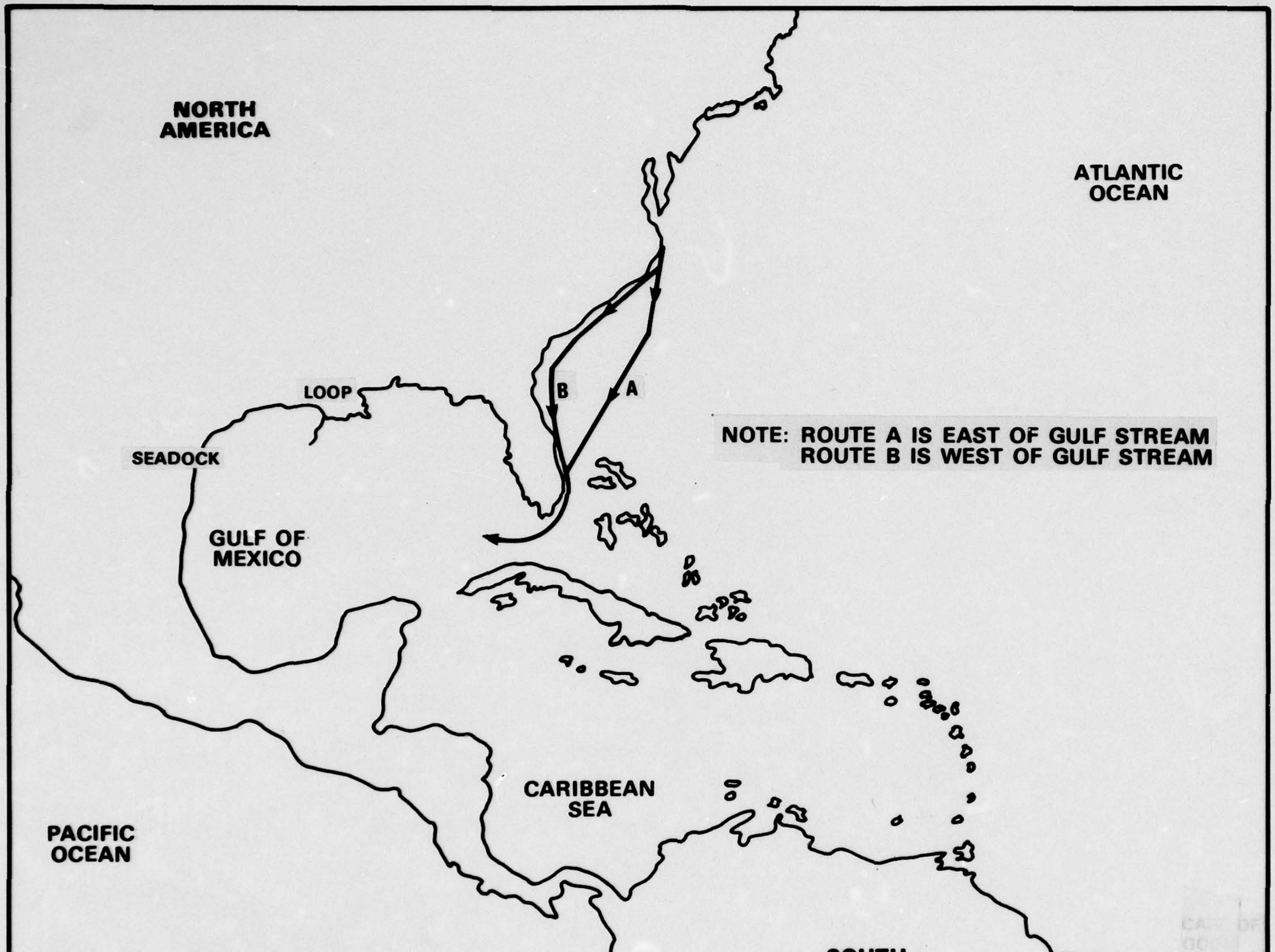
As the Florida Current is crossed between Mantanilla Shoal and the Florida east coast, a sharp lookout is necessary for northbound vessel traffic taking advantage of the Florida Current's strongest portion which, at this point, is about 15 miles from the Florida coast. On this leg of the route, also, frequent fixing of the vessel's position is necessary to allow a course to be steered which counteracts the strong northerly set of the Florida Current. As the Florida coast is approached, an alert lookout is necessary to detect southbound vessels close to the coast which are on the inside route. Hazards for the portion of the route from Fowey Rocks to Dry Tortugas have been covered previously and will not be repeated.

Route No. 2 (route "A" on figure VI-10) passes somewhat further to the west of Mantanilla Shoal than Route No. 1, however, the cautions concerning this dangerous reef are still applicable. As the southbound coastal traffic is joined, the hazards from Jupiter Inlet to Fowey Rocks are grounding along the Florida Coast, since it is passed very close aboard, and the large numbers of pleasure craft which can be expected from the heavily populated Florida beach resorts. Hazards for the portion of the route from Fowey Rocks to Dry Tortugas have been covered previously and will not be repeated.

Route No. 3 (route "B" on figure VI-10) is the same as Route No. 2 with the exception of an additional 30 miles of navigation close to the Florida coast from Fort Pierce to Jupiter Inlet in which portion grounding and large numbers of pleasure craft are the major hazards.

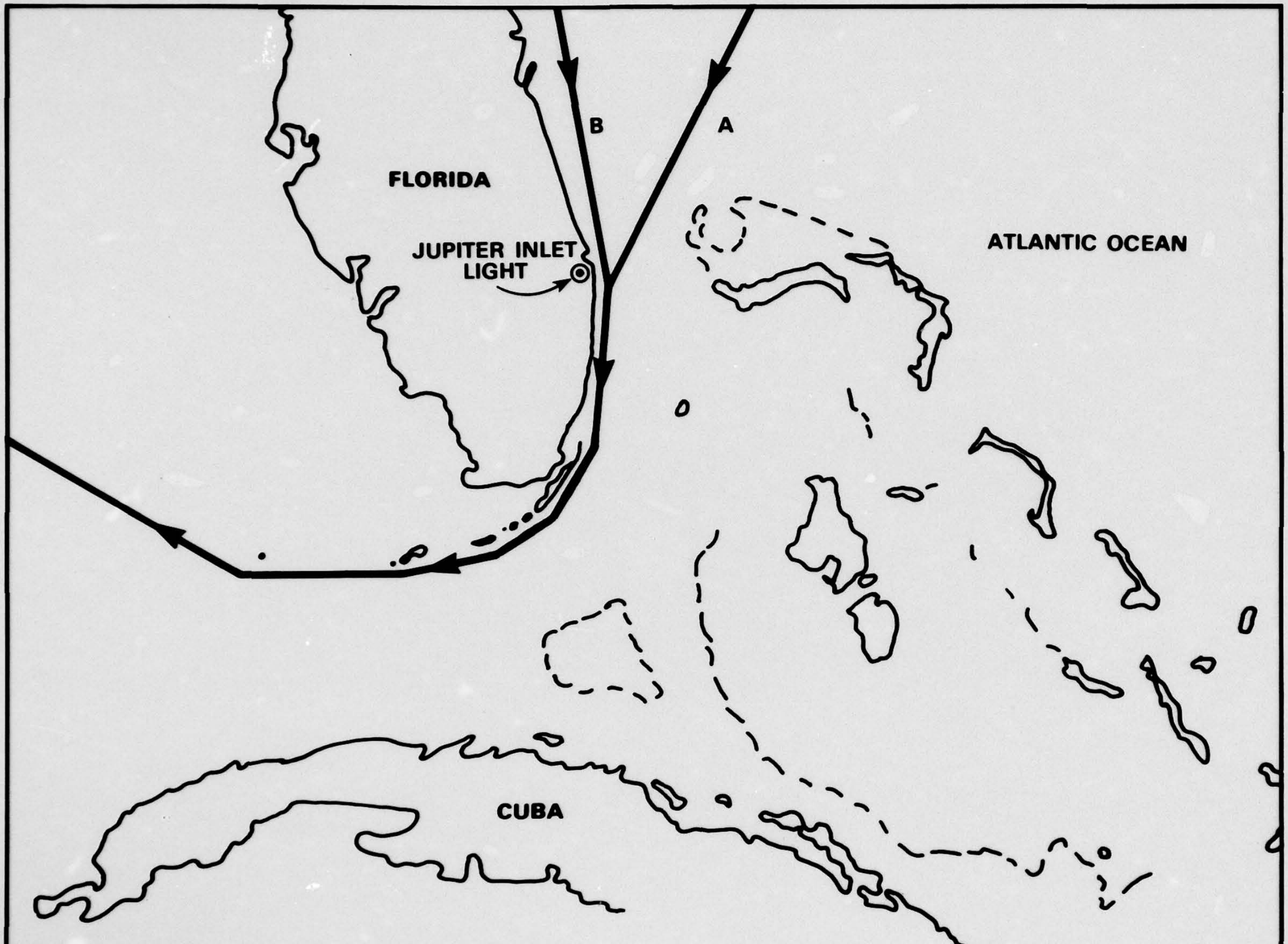
(5) <u>Routes from the East Coast of the U.S. to the Gulf of Mexico</u>

These routes have been previously explained as portions of other routes. Figures VI-12 and VI-13 show these routes. Since they complement one another, figure VI-14 is included to show the return route to the East Coast of the U.S. which takes advantage of the main axis of the Florida Current and the Gulf Stream. Hazards over these routes have been discussed in previous route descriptions.



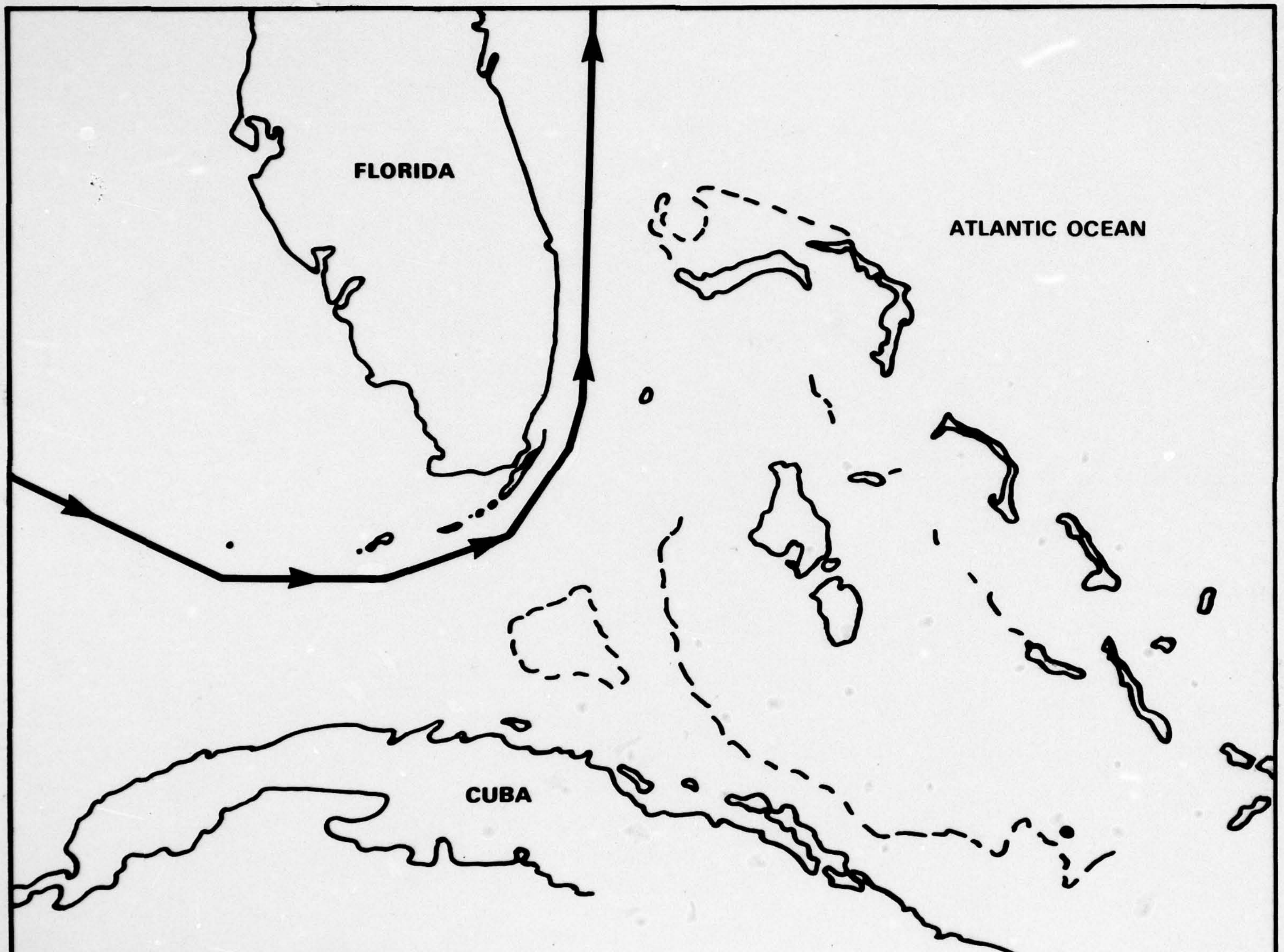
SOURCE: *U.S. Coast Pilot No. 4.* National Oceanic and Atmospheric Administration, Washington, D.C., 1977.

FIGURE VI-12. RECOMMENDED ROUTES EAST COAST OF U.S. TO KEY WEST



SOURCE: *U.S. Coast Pilot No. 4,* National Oceanic and Atmospheric Administration, Washington, D.C., 1977.

FIGURE VI-13. RECOMMENDED ROUTES EAST COAST OF U.S. TO KEY WEST—ROUTE A TO EAST OF GULF STREAM; ROUTE B TO WEST



SOURCE: *U.S. Coast Pilot No. 4,* National Oceanic and Atmospheric Administration, Washington, D.C., 1977.

FIGURE VI-14. RECOMMENDED ROUTE, KEY WEST TO EAST COAST OF U.S. VIA GULF STREAM

(6) Routes from the Straits of Florida to LOOP

A vessel leaving the Straits of Florida bound for LOOP would be faced with a choice of several routes. If he is unfamiliar with the area, he would probably set a course from Dry Tortugas for the southern entrance to the LOOP safety fairway following this fairway to the LOOP traffic separation scheme. In this way, he would be assured of passing through an area free of offshore structures. His principal hazards on this route would be other vessels crossing the Gulf. Since the use of safety fairways by vessels is not mandatory, however, he would have no assurance that he would not meet other vessels crossing these fairways. If he is familiar with the Gulf of Mexico area, he may choose to follow a course from Dry Tortugas direct to the LOOP traffic separation scheme, and thus shorten his trip by 50 to 60 miles. If he elects to do this, however, the last 20 miles would be through an area of offshore structures and some underwater obstructions, which transit should not be attempted by those without local knowledge. Just prior to entering this area, he would be crossing the traffic pattern for the Southwest Pass Entrance to the Mississippi River and could expect to encounter vessels entering and leaving this estuary.

It should be pointed out, also, that vessels may well select courses which fall anywhere within these southerly and northerly limits depending upon their familiarity with the area. Complete dependence need not be placed on celestial navigation over these routes; a new Loran-C chain now provides coverage of the Gulf of Mexico, and Loran-A coverage will continue until December 1980.

(7) Routes from the Straits of Florida to SEADOCK

A vessel leaving the Straits of Florida bound for SEADOCK could also select a range of courses as previously discussed for LOOP, depending upon his familiarity with the area, with the most direct route being to the entrance to the SEADOCK traffic separation scheme. The northern most route, however, crosses a number of shoal areas, most notably West Flower Garden Bank and East Flower Garden Bank, with 10 and 9 fathoms, respectively, in addition to an area of many offshore platforms. This area should be transited with caution and should not be attempted at all by those without local knowledge. Until the safety fairways are crossed, the principal hazard of the Gulf transit is other vessels crossing the Gulf. As the SEADOCK area is approached, a significant amount of vessel traffic may be expected due to its proximity to Galveston, Houston, and Freeport.

(8) Routes From LOOP and SEADOCK to the Straits of Florida

Vessels leaving LOOP and SEADOCK bound for the Straits of Florida can select the range of routes previously discussed, depending upon their familiarity with the hazards in the area of each of these deepwater ports.

(9) Eastbound Routes Through the Straits of Florida

Upon reaching the area of Dry Tortugas, vessels using Nicholas Channel will follow a direct route to the entrance steering a course which will counteract the easterly set of the Florida Current and pass well clear of Cay Sal Bank. From Dry Tortugas, vessels using Providence Channel or the northern entrance to the Straits of Florida follow the main axis of the Florida Current remaining about 8 miles off the Florida reefs, and passing Fowey Rocks at a distance of 10 to 12 miles. At this point, vessels using Providence Channel steer for a point 7 miles northwest of Great Isaac. Low-powered vessels proceeding to Northern Europe and vessels proceeding to Gibraltar (North Africa) steer for a point 10 miles northwest of Mantanilla Shoal, thence great circle. Fully powered vessels proceeding to Northern Europe continue following the Florida Current passing Jupiter Inlet at a distance of 15 miles, thence the main axis of the Florida Current. Along these routes, crossing westbound vessel traffic will be encountered exiting from Nicholas Channel and Providence Channel. At Mantanilla Shoal, there is a probability of meeting westbound traffic entering the Straits of Florida.

(10) General Hazards

Although tankers leaving the Gulf of Mexico in ballast are a potential hazard, they will be following, as will other vessels, the main axis of the Florida Current in the Straits of Florida to take advantage of the 3 to 4 knots increase in speed and remain about 8 miles off the Florida reefs, passing Fowey Rocks at a distance of 10 to 12 miles and Jupiter Inlet Light at 15 miles,[1] if transiting the entire length of the strait. Except for several cross-over points, these tankers in ballast and other vessels will be widely separated from incoming loaded tankers and other traffic which will try not only to avoid the Florida Current's full strength, but also in some instances take advantage of a counter current by following the Florida coast and the Florida Keys as close as safe navigation permits. The

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1. U.S. Department of Commerce. United States Coast Pilot 4, Atlantic Coast, Cape Henry to Key West, Fifteenth Edition, Washington, D.C.: Superintendent of Documents, 1977, p. 63.

Florida Current, therefore, actually creates a de facto traffic separation scheme in the Straits of Florida with cross-over or junction points in the area south of Dry Tortugas from Fowey Rocks to Carysford Reef (just south of Miami) and between Jupiter Inlet and Hillsborough Inlet (30 to 70 miles north of Miami). These latter cross-over points are apparently due to southbound vessels entering the Straits of Florida north of the Bahamas and crossing the Gulf Stream almost immediately after clearing Mantanilla Shoal or continuing southward to the east of the main axis of the Florida Current past Great Isaac and joining the traffic exiting from Providence Channel before heading southwest for the Fowey Rocks/Carysford Reef area. The area to the south and west of Dry Tortugas is a major junction point for vessels entering and leaving the Gulf of Mexico via the Straits of Florida. These traffic patterns have, in general, been borne out by actual observations.[1]

Hazards which are common to all water navigation area, such as floating or partially submerged debris, have not been mentioned as specific hazards; however, an inspection of Weekly Notices to Mariners indicates they are present from time to time in the Straits of Florida and the Gulf of Mexico. Only those hazards which are considered to be peculiar to the area have been included in this discussion, errors in judgment, for example, are constant and potentially catastrophic hazards; however, they can occur at any time, on any ship, in any body of water.

c. Superimposed on all of the above vessel routing information is the little-publicized, but widely used method of routing vessels to avoid bad weather. The U.S. Navy has such a system for its own vessels called Optimum Track Ship Routing (OTSR). There are also a number of private concerns which provide this same type of service to commercial shipping. It has been estimated that 20-25 percent of the ocean-going vessels use such systems on a regular basis. Routing such as this could cause great variance in the previously discussed vessel traffic routes, particularly in the hurricane season. (For a discussion of hurricanes and commercial vessel weather routing, see section IV.D on weather and currents.)

d. Figures VI-15 and VI-16 show a composite of the ship routes into and out of the Gulf of Mexico which have been individually described previously.

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1. Vessel Traffic Study of Florida Straits. Conducted by Commander, Seventh Coast Guard District (mep) May - September 1976, transmitted by Commander, Seventh Coast Guard District (mep) letter to Commandant (G-WDWP) dated September 10, 1976, file 16450/08.

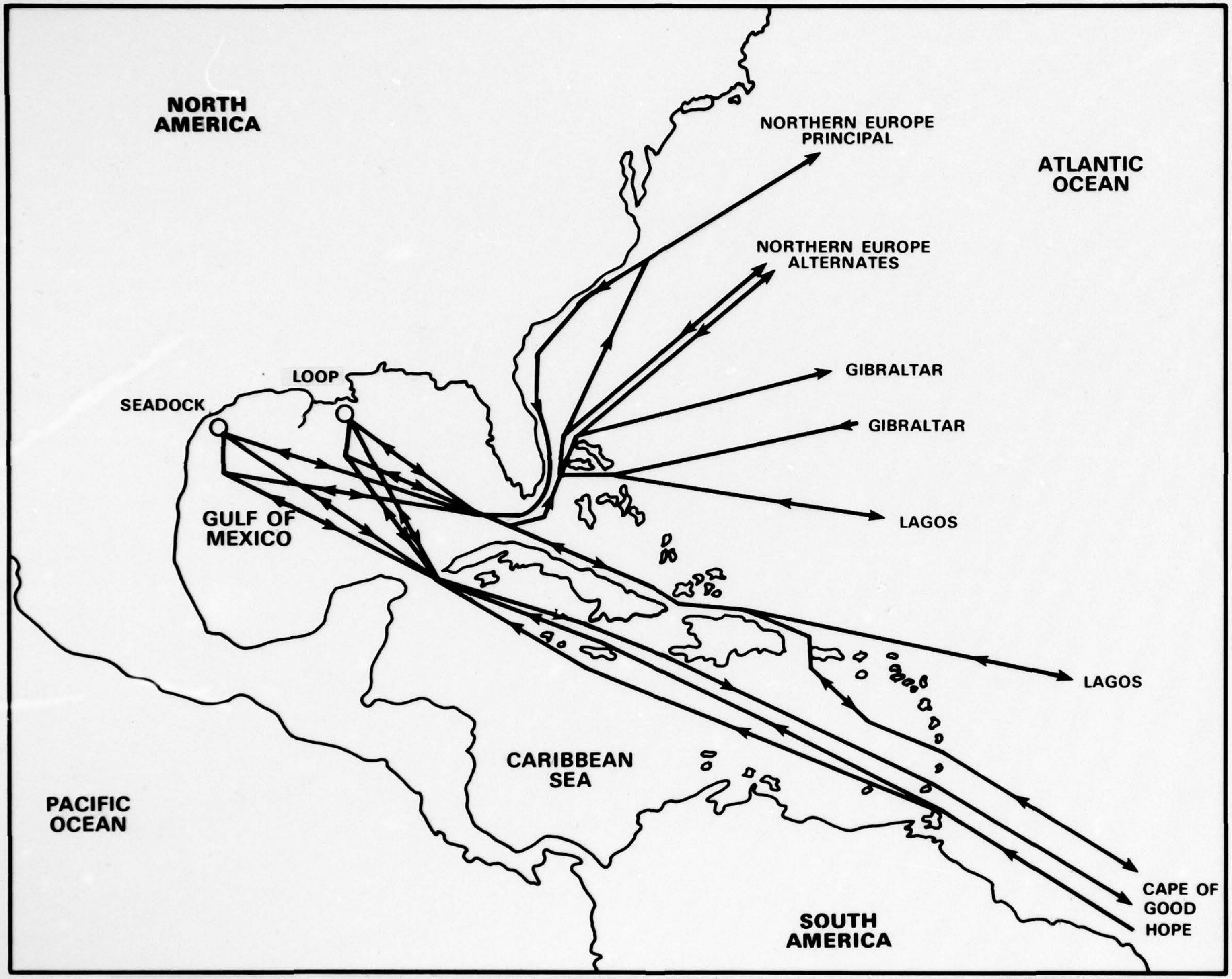


FIGURE VI-15. PRINCIPAL VESSEL ROUTES TO AND FROM THE GULF OF MEXICO

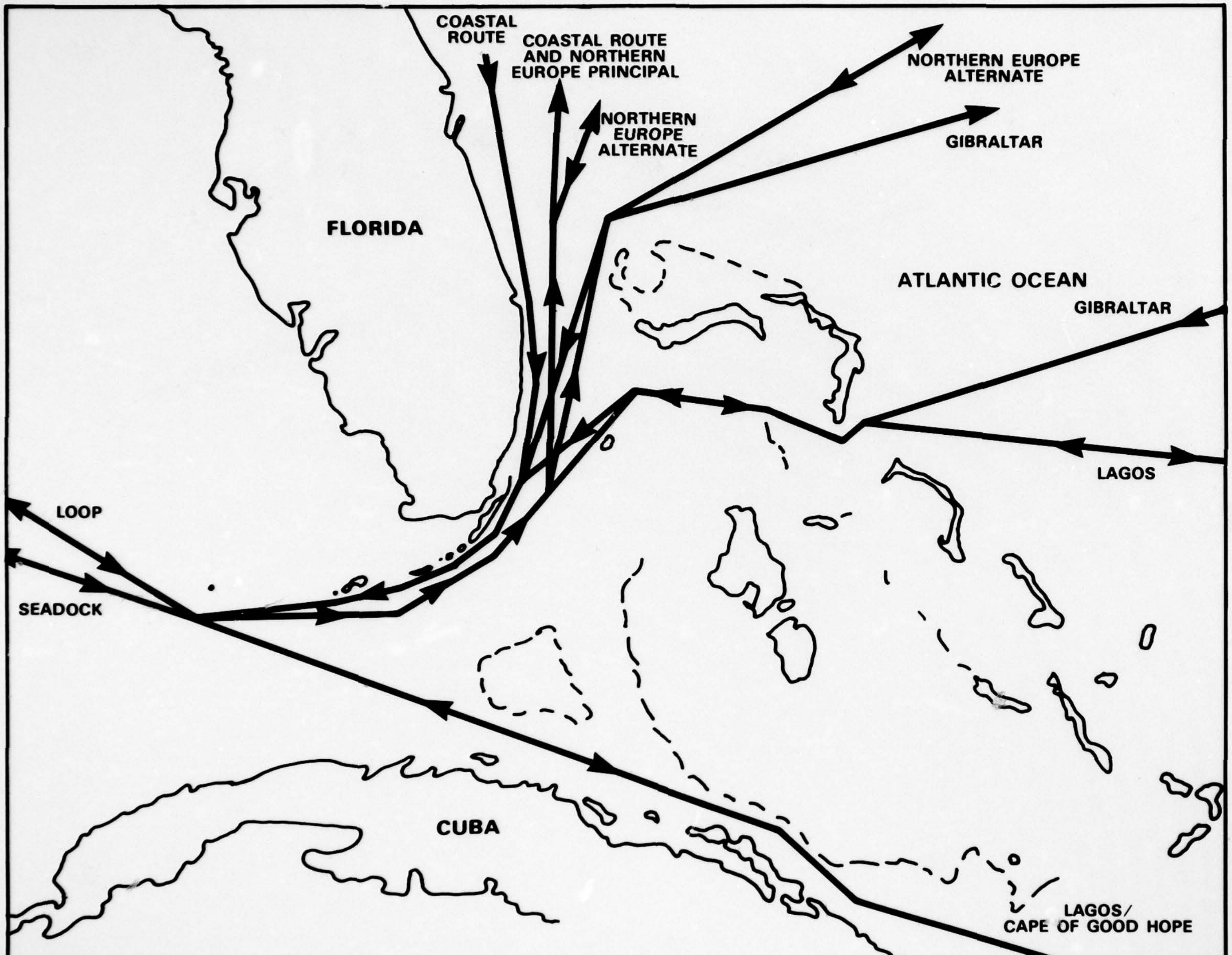
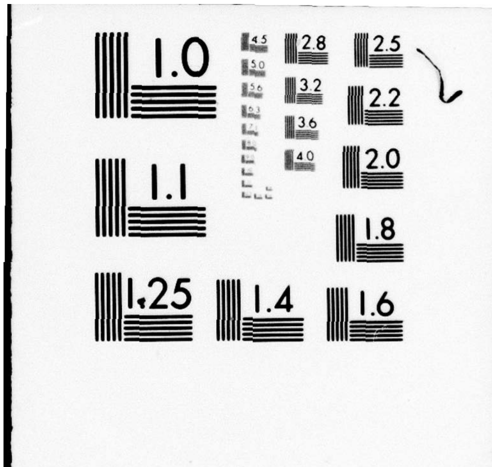


FIGURE VI-16. PRINCIPAL VESSEL ROUTES IN THE STRAITS OF FLORIDA

(1951) (1966)

AD-A074 529 PLANNING RESEARCH CORP MCLEAN VA F/G 15/5
DEEPWATER PORTS APPROACH/EXIT HAZARD AND RISK ASSESSMENT.(U)
FEB 79 W E FARAGHER, J T PIZZO, L R REINBURG DOT-CG-60351-A
UNCLASSIFIED USCG-D-6-79 NL

3 OF 5
ADA 074529



MICROCOPY RESOLUTION TEST CHART

2. Actual Ship Transits

a. Purpose and Scope

The previous section, the "paper transit" of the vessel routes into and out of the Gulf of Mexico was based upon literature research of the subject and was, in effect, a simulation of vessel transits of these routes. As stated in the preamble to that section, this "paper transit" was the pre-voyage preparation which a prudent mariner would make prior to taking a vessel over these routes. There are in existence charts and other publications which contain up-to-date information concerning most ocean areas of the world. It was this body of literature which was researched to analyze the various vessel routes into and out of the Gulf of Mexico. This section will discuss actual observations obtained from viewing at first hand the track of a large vessel transiting the Straits of Florida and the Gulf of Mexico and, in addition, touring the Arabian American Oil Company deepwater terminal at Ras Tanura, Saudi Arabia. Ras Tanura was chosen for study since it's installation at Juaymah resembles closely the facilities which are planned at both LOOP and SEADOCK. During the tour of Juaymah, observers rode on a 407,000 DWT VLCC from the deepwater sea island at Ras Tanura to the single-point mooring facility at Juaymah 15 miles to the north, witnessing the approach to the mooring and complete hook-up prior to the commencement of the oil pumping operation. The purpose of the actual observation was not only to obtain some measure of validation of the "paper transit" in the previous section, but also to view the actual operation of a deepwater port similar to both LOOP and SEADOCK in order to determine if any useful information could be obtained from comparing these operations with those planned for the two Gulf of Mexico deepwater ports.

b. Ras Tanura/Juaymah, Saudi, Arabia

The Arabian American Oil Company (ARAMCO) deepwater port at Ras Tanura, Saudi Arabia is located on the southern coast of the Persian Gulf, just northwest of Bahrein. This port was first constructed in 1939 to export the crude oil discovered in eastern Saudi Arabia several years earlier. In 1977, ARAMCO loaded 3.3 billion barrels of crude oil on tankers calling at Ras Tanura. Figure VI-17 is a chart of the Ras Tanura area showing its deepwater piers, bottom center, which can accommodate vessels alongside up to 100,000 DWT. The sea island, almost a mile in length, can accommodate much larger vessels, however, the channel depth limits the larger vessels to a maximum draft of 69 feet. These larger vessels must, therefore, sometimes take on partial loads at the sea island and top off at the

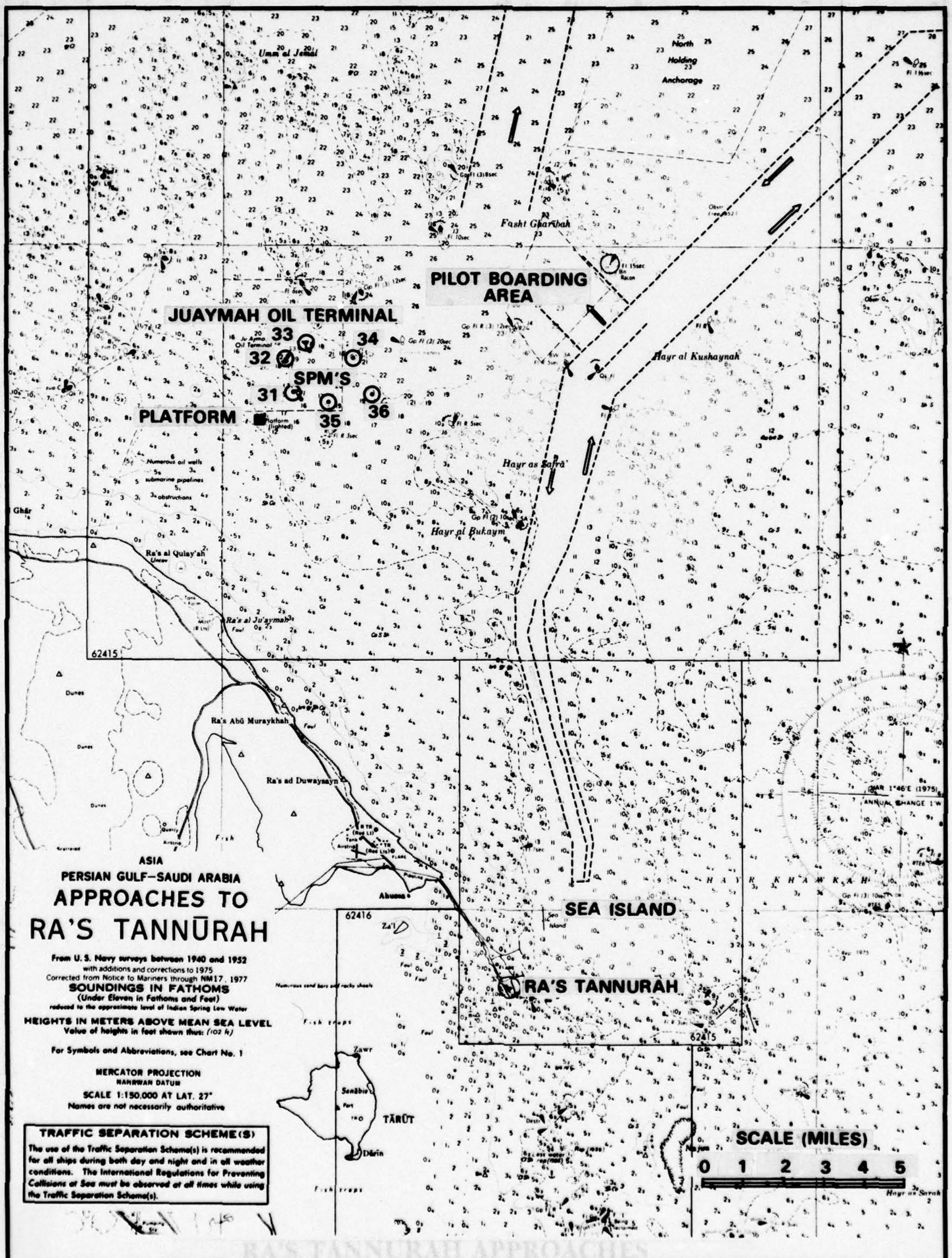


FIGURE VI-17. RA'S TANNURAH APPROACHES

(197) (198)

Juaymah single-point mooring facility 15 miles to the north which can handle the largest vessels now operating (e.g., about 500,000 DWT).

Vessels bound for both Ras Tanura and Juaymah enter in the same portion of the traffic separation scheme as shown in figure VI-17. The pilot boarding area for Juaymah is in the top center of the figure VI-17. Vessels proceeding to Ras Tanura transit the entire length of the channel and pick up pilots just north of the sea island. Vessels departing Juaymah use the one-way traffic separation scheme to the northeast of the facility, while vessels leaving the piers and the sea island use the eastern portion of the traffic separation scheme. Vessels are required to do their own piloting in the channels and traffic separation schemes; ARAMCO pilots are furnished only for mooring and unmooring at both Ras Tanura and Juaymah. Although tugs are used at Ras Tanura routinely for mooring and unmooring, they are not used at Juaymah except in emergencies. Tugs available at Ras Tanura are one Voith-Schneider (trainable water jet) tug, one tug leased from McAllister, two 3,000 horsepower single-screw tugs, and three 4,000 horsepower single-screw tugs.

English is the standard language for all port operations. Vessels entering port contact Ras Tanura control on channel 16 (156.8 MHz VHF-FM) and shift to channel 10 for working. Continuous surface search radar surveillance is maintained at both Ras Tanura and Juaymah. There is a dual installation at both locations of Decca Harbor Radar, one of which is kept on the 6-mile scale, and the other on the 12-mile scale. The vessel traffic is not controlled, only advised. Vessels are expected to take this "advice," however, and if they do not, ARAMCO writes to their owners formally complaining of noncooperation. Ras Tanura/Juaymah handles about 4,000 tankers a year, and for the last 15 years there has been no serious accident or massive oil spill. According to Ras Tanura officials there has never been a vessel collision with a pilot on board. There are a total of over 60 pilots at Ras Tanura and Juaymah.

There is an extensive on-the-job training program involving instruction and "test" piloting. The most experienced pilots randomly ride vessels and check the performance of junior pilots. Before non-Saudi Arabians are hired as pilots, they must have both a master's license and a pilot's license. Since Saudi Arabia has no licensing requirements, and there is little opportunity to gain sea experience, there is a special training and qualification program for Saudis. Initial training in the basics of ship and small boat handling is through the U.S. Navy Mission in Dhahran. On-the-job training then progresses to the smallest tugs, 55 feet in

length, then the 90-foot docking tugs. After this, Saudi pilot trainees are sent to the College of Nautical Studies in Southhampton, England, followed by 6-month assignments to ARAMCO shareholder ships. Upon completion of this training, there is a 3-year period of on-the-job training as pilots. There are now seven Saudi pilots who have come up through this system, and three are in the final 3-year training period. One of the Saudis is a senior harbor pilot.

Although Petroleum Helicopter Services of Lafayette, Louisiana has a contract with ARAMCO to use helicopters for transportation to offshore oil rigs, they are not used to transport pilots to vessels or for anything other than emergency services to the Juaymah oil structure. There were two reasons for this; insurance cost, and lack of structural strength in the platform.

Ras Tanura is, perhaps, the only large commercial port in the world which makes no charges for its services with one exception, that is, companies whose ships use this port are billed for maintenance of aids to navigation. A private concern, Middle Eastern Navigation System (MENAS) maintains all of the aids of navigation in the Gulf waters of Saudi Arabia. The basic positioning system used is Raydist. The shore radar at Ras Tanura has a "Decca Spot System" to monitor buoy positions. The innermost portion of the Ras Tanura channel is 800 feet wide although many of the ships using this channel are 1,200 to 1,300 feet long. According to local authorities, only two vessels have gone aground in the harbor in the last 15 years, and only minor damage was incurred in both instances.

Single-point mooring hawser breakage at Juaymah has been a problem. This has led to a number of actions, such as establishing a hawser testing program, installing hawser load monitoring systems (not yet completed), increasing the strength of the mooring line to four parts of 15-inch double braided nylon from two, and a plan ultimately to increase this further to four parts of 18-inch double braided nylon. There is a local, severe, wind condition known as a "shamal," which arises with no warning. This has been the main cause of these breakouts. When the wind reaches 40 knots, disconnection is started. These shamals cause VLCCs to yaw, particularly when they are light. It is this yawing which causes the vessel to "fetch up" on the mooring resulting in parted moorings. Experimentation has been conducted having one of the small tugs put a line on the vessel's stern taking a strain to prevent yawing. This has been effective; however, the shamal occurs so quickly that there is often insufficient time to follow this practice. EXXON Research and Engineering Company has been working on this overall problem.

In calm weather there has been a problem with vessel riding up against buoys, tipping the swivel, which jams, putting a kink in the hose. In addition, and also in very calm weather, the swivel on a CALM does not turn. This does not cause any problems up to 90^{o}, but beyond that, unless it is corrected by a utility boat, the hose kinks.

ARAMCO does not sell petroleum; it is responsible for production, loading, and through ARAMCO Services Company in Houston, coordinating the ordering and delivery. Vessels taking on oil cargoes are requested to notify ARMCO 72 hours before their estimated time of arrival (ETA), updating at 48 hours. They are required to give 24-hour notice of ETA. If this is not done, ARAMCO has the option of delaying delivery by 24 hours. This is done to schedule vessels and cargoes at berths. Every attempt is made to berth vessels upon arrival. Each vessel is required to have a local agent and certify that the crew is free of communicable disease before pratique is granted.

ARAMCO has its own Marine Radio Facility which maintains a continuous guard of 500 KHz and the 8, 12 and 16 MHz maritime mobile calling bands. Until a recent change in international radio regulations, these bands were swept manually at three CW ship/shore positions. Discrete calling frequencies are now guarded. Although 500 KHz is guarded, the station has no MF working frequency. In the spring of 1978 there were about 50 vessels on the traffic list which is a normal load. The station makes a CW broadcast at 4:30 a.m. and 4:30 p.m. local time of weather and marine information. According to the station manager, the weather comes from "IMCO Bahrein," and the marine information from the Port Captain, Ras Tanura. The communication facility adjacent to the radio station has a very sophisticated automatic teletype system just recently installed to replace a manual tape relay. All major ARAMCO facilities are in the system including (by satellite) New York, Houston, The Hague, and Jiddah. Three telex terminals complete the facility and are used not only for company business, but also are open to public correspondence. A completely new facility is scheduled to be completed by the last quarter of 1979 at which time all equipment will be replaced, an MF working frequency will be activated, and a guard of the 4 MHz maritime mobile band will be added.

c. Comparison of LOOP, SEADOCK and Juaymah

In figure VI-18, a matrix has been developed to compare the physical and operating characteristics of LOOP, SEADOCK and Juaymah with possible problem areas and comments following each characteristic.

CHARACTERISTIC	LOOP	SEADOCK	JUAYMAH	POSSIBLE PROBLEM AREAS; COMMENTS
Location	Exposed; 13.5 miles from Louisiana coast; 18 miles south of Grande Isle.	Exposed; 20 miles from Texas coast; 26 miles south of Freeport.	Exposed; 6 miles from coast; 18 miles northwest of Ras Tanura, Saudi Arabia.	Juaymah average port closings due to weather 275 hours (11.5 days) per year due to exposed location. Gulf of Mexico larger than Persian Gulf, therefore greater fetch.
Size	Six SPM; 1.1 miles apart. All buoys 1.35 miles from platform.	Six SPM; 1.3 miles apart. All buoys 1.3 miles from platform.	Six SPM; distance apart varies from .8 to 1.5 miles. 1.25 miles from platform to nearest buoy.	LOOP Phase I calls for 3 SPM. SEADOCK Phase I calls for 4 SPM.
Shape	Circular; 14,500 feet in radius.	Circular; 14,500 feet in radius.	Elliptical, major axis 2.75 miles, minor axis 2 miles.	Juaymah configuration constrained by adjacent shoals.
Location of Platform	In center of SPM area.	In center of SPM area.	Outside SPM area.	Juaymah intentionally designed with platform outside SPM area to reduce hazard from vessels not under command.
Type of Mooring	Six SALM	Six SALM.	Four CALM, two SALM.	SALM is a new development in SPM's.
Traffic Separation Scheme	Present configuration 6 miles long, 2 miles wide divided in middle to separate incoming and outgoing traffic. Safety fairway 63 miles long and 2 miles wide.	Present configuration 5.5 miles long, 2 miles wide divided in middle to separate incoming and outgoing traffic. Safety fairway 58 miles long and 2 miles wide.	Widely separated incoming and outgoing traffic.	Sixty-five degrees left turn required between Safety Fairway and Traffic Separation Scheme on entering LOOP, and reverse on exit. Thirty-four degrees turns required for SEADOCK. Consider one way alternating traffic vice two-way traffic.
Traffic Density	405 vessels per year anticipated during first five years.	569 vessels per year anticipated during first five years.	Statistics not available. Based on throughput estimate, approximately 900 vessels per year. (Approximately 5,000 vessels per year visit Ras Tanura/Juaymah.)	LOOP initial throughput 1.4 MMBD. LOOP ultimate throughput 3.4 MMBD. SEADOCK initial throughput 2.5 MMBD. SEADOCK ultimate throughput 4.0 MMBD. Juaymah throughput 3.0 MMBD.
Depth of Water	104 to 115 feet.	96 to 105 feet.	123 to 135 feet.	Largest tankers now in operation can be accommodated at LOOP and SEADOCK, although most VLCC traffic will be in the 200,000 to 325,000 DWT range for the foreseeable future.
Pilotage	Required at entrance to TSS (6 miles outside SPM area). No tanker may be underway in Safety Zone or that part of the TSS that is within 5 miles of the Safety Zone without a pilot. *	Required at entrance to TSS (5.5 miles outside SPM area). No tanker may be underway in the Safety Zone or that part of the TSS that is within 5 miles of the Safety Zone without a pilot. *	Required from arrival at boarding area approximately 5 miles east of SPM area until departure at outgoing TSS entrance approximately 5 miles north of SPM area.	* At LOOP and SEADOCK the pilot is termed a Mooring Master. At Juaymah the vessel must do its own piloting during transit of the TSS, which is two widely separated lanes, 30 miles each in length.
Pilot's Method of Boarding	Pilot boat	Pilot boat.	Pilot boat	Helicopter may be used at LOOP. Use of helicopter possible at SEADOCK. Helicopter has been considered at Juaymah and rejected as too expensive.

FIGURE VI-18. COMPARISON OF LOOP, SEADOCK, AND JUAYMAH

COMPARISON OF LOOP, SEADOCK, AND JUAYMAH

Page two

CHARACTERISTIC	LOOP	SEADOCK	JUAYMAH	POSSIBLE PROBLEM AREAS: COMMENTS
Weather	Four-month hurricane season July through October. Some severe storms and fog in winter months.	Four-month hurricane season July through October. Some severe storms and fog in winter months.	Local severe, clear weather wind condition called "shamel". Sandstorms. Some coastal fog.	Vessels should monitor weather broadcasts regularly when in Gulf of Mexico and Caribbean area, and be prepared to take evasive action as necessary.
Other Vessels	Located in excellent shrimping area. Some Menhaden fishing.	Located in excellent shrimping area.	Some transient fishing vessels.	Potential for much more fishing vessel activity at LOOP and SEADOCK than at Juaymah.
Navigation Hazards	Numerous oil rigs in the area.	Numerous oil rigs in the area.	Numerous shoals in the area.	Oil rigs pose navigation hazards at LOOP and SEADOCK.
Navigation Aids	Will be covered by new Loran-C chain by October 1978. Safety Fairway not buoyed. Anchorage and TSS buoyed. Platform will have fog signal, obstruction lights, Racon, visual beacon, and X-band surveillance radar.	Will be covered by new Loran-C chain by October 1978. Safety Fairway not buoyed. Anchorage and TSS buoyed. Platform will have fog signal, obstruction lights, a rotating beacon, Racon, and X-band surveillance rader. (S-band radar may also be added.	Covered by Decca chain. Channels and obstructions well marked by lighted aids. X-band radar surveillance from platform. Buoy positions continuously monitored by Decca Dot system.	Provide for frequent monitoring of floating navigation aids positions. Aids to navigation at United States deepwater ports must meet requirements in 33 CFR 149.701 through 149.799.
Traffic Control	Yes, in Safety Zone and TSS.	Yes, in Safety Zone and TSS.	Yes, in SPM area.	Possible legal problems at LOOP and SEADOCK, particularly with transient non-port patrons.
Tug Standing By	No	No	No	Tugs not available on short notice at Juaymah. This has caused no major casualties.
Load Monitoring on Mooring	Planned	Unknown	Being installed	Determine conditions under which emergency breakaway takes place.
Jurisdictional Considerations	Located outside territorial sea.	Located outside territorial sea.	Located in territorial sea.	Legal aspects of jurisdiction over port patrons, as well as transient vessels should be assessed.
Bunkering	Bunkering from a service vessel.	Bunkering from a service vessel.	Bunkering hose on each SPM.	Reassess whether bunkering should or could be done by hose at buoy.
Stores	By supply vessel.	By supply vessel.	Not available.	Small craft are not allowed in the vicinity of a tanker and no one is permitted to board or leave a tanker while cargo loading operations are in progress at Juaymah.
Radio Communications	Ship-shore HF-SSB and VHF-FM. Long range communications with vessels through commercial radio stations via TWX. Pilot carries portable VHF-FM.	Ship-shore VHF-FM. Long range communications with vessels through commercial radio stations via TELEX/TWX. Pilot carries portable VHF-FM.	ARAMCO has own MF, HF radio station with land line teletype to Juaymah platform, and TELEX. Platform has ship-shore VHF-FM. Pilot carries portable VHF-FM.	Juaymah has its own, well-equipped radio station, subject to its control. LOOP and SEADOCK use commercial facilities.

FIGURE VI-18. (continued)

Figure VI-17 (continued)
COMPARISON OF LOOP, SEADOCK, AND JUAYMAH

Page three

CHARACTERISTIC	LOOP	SEADOCK	JUAYMAH	POSSIBLE PROBLEM AREAS: COMMENTS
Tsunami	None experienced.	None experienced.	None experienced.	No record of Tsunamis in Gulf of Mexico
Type of Facility	Crude oil receiving from ships.	Crude oil receiving from ships.	Crude oil delivery to ships.	Receiving facility somewhat dependent on delivery facility.
Hose Testing Facility	Yes	Yes	Yes	No significant difference.
SPM Inspection	Divers will inspect SPM underwater hose lines and risers regularly.	A regular schedule of inspections will be established, using divers and possibly CCTV and deep diving submersibles.	Weekly and on arrival and after departure of VLCC, using divers.	Worthwhile preventive measures.

FIGURE VI-18. (continued)

d. Transit of the Straits of Florida and the Gulf of Mexico

The actual transit of the Straits of Florida and the Gulf of Mexico was made on a 20,000 GT, 600-foot chemical tanker which left Baltimore on June 12, 1978 and arrived at Lake Charles, Louisiana on June 17, 1978. Known as a "drugstore" tanker, this vessel is equipped with 27 cargo tanks carrying a diverse and constantly varying inventory of chemicals and petroleum products such as lube oil, benzene, caustic soda, and naphtha. It regularly carries chemicals from the U.S. Gulf Coast to the U.S. East Coast travelling in ballast on the return trip.

After departing the Capes of the Chesapeake, the vessel followed a coastal route to Diamond Shoal Light which was passed 3 miles abeam at about 10:00 a.m. The washing of cargo tanks began at about 9:00 a.m. From Cape Hatteras the vessel has two routes to the Straits of Florida, one for good weather which goes several hundred miles to sea, and one for bad weather which hugs the coast to pick up a lee from the seas. After rounding Cape Hatteras, since the voyage was in June and the weather excellent, the outside route was taken closely approximating the track recommended by the U.S. Coast Pilot, and previously described under the "paper transit."

The tank washing operation continued from the area of the Capes of the Chesapeake until just before entering the Straits of Florida. This was an all-hands operation which lasted from before dawn until late at night. Bad weather has caused much delay in this procedure due to a loss of stability from empty cargo tanks. After the tank cleaning, the remainder of the trip was used for manual cleaning of the tanks followed by ventilation with compressed air and fans.

At approximately 8:30 p.m., June 14, 1978 Mantanilla Shoal Lighted Buoy was passed abeam to port at a range of 8 miles. This is the northern-most portion of the Bahama Islands and the northern part of the Straits of Florida. Although the regular track of the vessel is usually in a south-southwesterly course direct from Mantanilla Shoal for Fowey Rocks Light just south of Miami, during the night the ship crossed on a more westerly course to a landfall on Jupiter Inlet. According to the master, this was done not only to reduce the time spent in the main axis of the Gulf Stream, but also to avoid the vessel traffic which uses Providence Channel.

At about 5:00 a.m. on June 15, 1978 the vessel was 2.5 miles east of Fowey Rocks Light in a southerly heading. The vessel had passed so close inshore off Miami Beach that neon signs in buildings could be read without

binoculars. The master tries to pass Miami late at night or very early in the morning to avoid the very large number of pleasure craft in that area which he considers a significant hazard. About a half hour after this, intermittent rain squalls were experienced with thunder and lightening. These squalls continued over the next hour and a half during which time visibility was reduced to less than 1 mile.

Although the weather during most of the remainder of the trip along the Florida Keys was bright and clear, one more rain squall was encountered. The track followed was essentially a series of tangents to the reef line 20 to 30 miles in length remaining 1 to 2 miles from the reefs. This continued to Dry Tortugas which was passed about 6:00 p.m., June 15, 1978. Although the vessel was making turns for 16 knots, the countercurrent close to the reef resulted in a speed over the ground of 17-18 knots as far as Dry Tortugas. During this passage from Fowey Rocks to Dry Tortugas a total of 46 large vessels were sighted. Forty-two of these were east and northbound following the axis of the Florida Current and the Gulf Stream. None passed closer than about 6 miles and some were as far out as 12 to 14 miles. In addition, two large vessels, a container ship and a cargo ship, were anchored just east of Dry Tortugas. The remaining two vessels were headed west, one was ahead being overtaken and the other was astern overtaking. Of the large vessels sighted, 10 were definitely identified as tankers, 2 of which were apparently VLCCs. All were headed east in ballast.

It became apparent, just south of Key West, that the vessel being overtaken, a large bulk carrier, was converging. Attempts to determine her intentions using flashing light and VHF FM channels 13 and 16 were unsuccessful even though during this time she had closed to ¼ mile. It did not appear that the bridge of the vessel being overtaken was manned. Shortly thereafter, people appeared on the bridge of the bulk carrier, and it began to slow. At this time, the observer vessel was about 1 mile south of the reef line and being overtaken by another large vessel. Maneuvering room was therefore severely restricted. It was apparent that the large bulk carrier was on automatic steering with the bridge unmanned; a very dangerous practice in pilot waters.

During the Straits of Florida passage, many pleasure craft were encountered, a number of whom with great effort crossed the vessel's bow close aboard from right to left. The master believes his biggest hazard on this route is pleasure craft. A commercial shrimping vessel with nets down was passed close aboard 2 miles off the reef just east of Key West entrance. As the vessel passed, the

shrimper got underway to fish in the area stirred up by the wake of the passing vessel. According to the mate on watch, shrimpers do this as a general rule since the wake stirs up the shrimp.

At Dry Tortugas, course was set for Lake Charles following the most direct route and not the safety fairways. It was explained by the master that the vessel comes through this area every 10 days to 2 weeks, and the route is a familiar one. After departing Dry Tortugas in the evening of June 15 until the first oil rig off the Texas Coast was sighted at about 10:00 p.m. on June 16, only three vessels were sighted, one going in the same direction and two on a reverse course. In the open sea area of the Gulf, the weather was calm and clear and the navigation was by Loran-A. After the oil rigs were sighted, the Loran-A equipment was put on automatic track on station 3H2 for a longitude line, and bearings were taken on the nearest structure to obtain fixes. By midnight, there were 30 to 40 oil rigs in view and many more on the 16-mile scale of the radar. There was also a considerable amount of radar interference on the 3 centimeter radar in the form of "spoking." According to the mate on watch, two of the largest oil rigs passed were not there on the previous trip and were not charted. By 6:00 a.m., about 15 miles south of the Calcasieu Pass Entrance, there were 50 oil rigs on the 16-mile scale of the radar, mostly to the northeast. The master advised that he had found this route by experimentation.

The vessel has a well-equipped radio shack for operation on medium frequency and high frequency CW and high frequency single sideband. The radio officer is also responsible for the maintenance of all electronic equipment. He prefers CW as being the most economical, efficient, and reliable means of communications. The vessel does not have a high volume of traffic. His normal way of delivering commercial traffic is through radio station WSL (New York). An alternate radio station is WCC (Boston), which he uses only as a last resort since he has difficulty establishing contact. He gets his weather from the station WSL CW broadcast, and obtains Gulf Stream positions from the Coast Guard Radio Station NMA (Miami) CW broadcast. The vessel is a regular participant in the AMVER program and sends weather observation reports to the U.S. Weather Bureau via Coast Guard Radio Stations NMN (Norfolk) or NMA (Miami).

The electronic and navigation equipment in the bridge includes the following:

- Raytheon Ray-50AR Remote unit VHF-FM which is fully synthesized (can operate on any channel).

The main transmitter receiver is located in the radio room. The entire time the vessel was underway this equipment was kept in operation, guarding channel 16, the international distress frequency, and 13, the bridge-to-bridge radio/telephone frequency. Weather and marine information broadcasts were monitored down the coast on VHF-FM from the Weather Bureau and the Coast Guard and were heard clearly during most of the trip. The NOAA VHF-FM Station KIH26 at Daytona Beach, for example, was heard loud and clear during daylight hours 180 miles away.

- Loran A/C - ITT Mackay Marine Type 4207A Serial F0360. This equipment is due to be replaced by a new Loran-C equipment. The Loran-C portion of the receiver was not in operating condition during the trip. Loran-A was used almost excusively for offshore navigation. The only celestial navigation was done by two cadets, one from Massachusetts Maritime Academy and one from Maine Maritime Academy, who were on board for training.
- Radio Direction Finder - RCA Model AR8714C, 190-270kHz, and 270-515kHz. Never observed to be used during trip.
- Course Recorder - Sperry.
- Gyro Compass - Sperry Mark 227 with bridge wing and steering repeaters, automatic steering.
- Surface Search Radar - Radio Marine Type CRM - N2C-30 - 10 centimeter.
- Surface Search Radar - No name plate - 3 centimeter.

The master of the vessel was asked about a company storm evasion policy, but apparently this company has none and prefers to rely on the experience and judgment of the master. The master declined to elaborate on his own personal storm evasion thoughts, saying only that each storm has different charac-

teristics, and he takes such evasive action as the current storm condition warrants, taking into consideration the general tactics recommended in Bowditch.

e. Hazards to Vessel Operation in the Straits of Florida and the Gulf of Mexico

Based on the literature search conducted during the "paper transit," the actual transits described above, and the seagoing background of the observer,[1] the matrices in figures VI-19 and VI-20 have been constructed to show the relative importance of the hazards, as classified in the Coast Guard Vessel/Casualty Reporting System (VCRS), to vessel operation in the Straits of Florida and the Gulf of Mexico. The Straits of Florida has been divided into three general geographic areas as shown in figure VI-19. These three areas have been further expanded to cover eastbound and westbound routes since the Florida Current forces vessels to hug the Florida Keys when westbound to not only avoid the current, but also take advantage of a counter current close to the reef line, and go 10 to 15 miles offshore when eastbound to benefit from the full force of the Florida Current. This de facto traffic separation scheme is discussed in greater detail earlier in this section under the "paper transit." The hazardous ratings in figure VI-19 in certain areas of the Straits of Florida reflect vessel traffic meeting areas which have developed somewhat naturally due to vessels crossing the Florida Current when entering the Straits from the north at Mantanilla Shoal, and from Providence Channel.

The highly hazardous ratings throughout figure VI-19 assigned to storms is due primarily to the threat of five to six hurricanes each year in the Gulf of Mexico/Caribbean Sea area, which make weather a primary hazard to safe vessel navigation. Table VI-2, "Vessel Casualties in the Gulf of Mexico, 1969-1977," shows that by number of occurrences, heavy or adverse weather ranks number three after personnel fault and restricted channel, however, if casualties caused by low visibility and currents are included with those due to adverse weather then weather becomes the second greatest cause of casualties. Frequency of occurrence, however, should not be the sole determinant of a hazard ranking; potential severity of the hazard must also be considered. The enormous potential destructive force of hurricanes make them clearly a primary hazard to vessel operations during the July

1. A retired Captain, U.S. Coast Guard, who has served on board six vessels, and has a total of six years command at sea in ocean-going vessels.

EXTERNAL HAZARD	STRAITS OF FLORIDA					
	WESTBOUND			EASTBOUND		
	Fort Pierce/ Mantanilla Shoal Miami/Providence Channel Entrance	Miami/Providence Channel Entrance to Key West/ Nicholas Channel Entrance	Key West/Nicholas Channel Entrance to Dry Tortugas	Dry Tortugas to Key West/Nicholas Channel Entrance	Key West/Nicholas Nicholas Channel Entrance to Miami/ Providence Channel	Miami/Providence Channel Entrance to Fort Pierce/ Mantanilla Shoal
Structures, vessels, etc.						
Floating debris or submerged objects	3	3	3	3	3	3
Fixed objects—piers, bridges	1	1	1	1	1	1
Offshore rigs	1	1	1	1	1	1
Single Point Moorings	1	1	1	1	1	1
Aids to navigation	2	1	1	1	1	2
Other vessels anchored or moored	3	3	2	1	1	1
Other vessels docking or undocking	1	1	1	1	1	1
Other vessels meeting	3	1	3	3	2	2
Other vessels crossing	5	2	2	5	2	5
Other vessels overtaking	1	1	1	1	1	1
Aids to Navigation						
Reliability	1	1	1	1	1	1
Adequacy	1	1	1	1	1	1
Environmental Weather						
Storms, heavy weather	5	5	5	5	5	5
Adverse weather	2	2	2	2	2	2
Low visibility	2	2	2	2	2	2
Restricted Maneuvering Room						
Channel	2	2	2	1	1	1
Congested area	5	2	5	5	2	5
Unusual Current						
Erratic	1	2	2	1	1	1
Strong Current	3	3	2	1	1	1
Depth Less Than Charted						
Charts Erroneous	3	2	2	1	1	3
Area shoaled/silted	5	1	1	1	1	3
Position of hazard doubtful	5	2	2	1	1	3
Bottom and Bank Effect						
Sheer	1	1	1	1	1	1
Suction	1	1	1	1	1	1
Bank Cushion	1	1	1	1	1	1
	59	43	46	43	36	49

HAZARD RATING: Highly hazardous = 5; Very hazardous = 4; Hazardous = 3; Not very hazardous = 2; Not hazardous = 1; and Unknown = 0.

FIGURE VI-19. SUBJECTIVE HAZARD RATINGS, STRAITS OF FLORIDA

EXTERNAL HAZARD	Gulf of Mexico Transit		Safety Fairway (including "short cuts")		Traffic Separation Scheme		DWP Safety Zone	
	LOOP	Seadock	LOOP	Seadock	LOOP	Seadock	LOOP	Seadock
<u>Structures, vessels, etc.</u>								
Floating debris, or submerged objects	3	3	3	3	1	1	1	1
Fixed objects—piers, bridges	1	1	1	1	1	1	1	1
Offshore rigs	5	5	5	5	1	1	2	2
Single point moorings	1	1	1	1	1	1	2	2
Aids to navigation	1	1	1	1	2	2	1	1
Other vessels anchored or moored	1	1	1	1	1	1	3	3
Other vessels docking or undocking	1	1	1	1	1	1	3	3
Other vessels meeting	2	2	2	2	1	1	1	1
Other vessels crossing	2	2	2	2	2	2	2	2
Other vessels overtaking	1	1	2	2	1	1	1	1
<u>Aids to Navigation</u>								
Reliability	1	1	1	1	1	1	1	1
Adequacy	1	1	1	1	1	1	1	1
<u>Environmental Weather</u>								
Storms, heavy weather	5	5	5	5	5	5	5	5
Adverse weather	2	2	2	2	3	3	3	3
Low Visibility	2	2	4	5	3	3	3	3
<u>Restricted Maneuvering Room</u>								
Channel	1	1	2	2	1	1	2	2
Congested Area	1	1	2	2	1	1	2	2
<u>Unusual Current</u>								
Erratic	1	1	2	2	2	2	2	2
Strong current	1	1	1	1	2	2	2	2
<u>Depth Less Than Charted</u>								
Charts Erroneous	1	1	1	1	1	1	1	1
Area shoaled/silted	1	1	1	5	1	1	1	1
Position of hazard doubtful	1	1	3	3	1	1	1	1
<u>Bottom and Bank Effect</u>								
Sheer	1	1	1	1	1	1	1	1
Suction	1	1	1	1	1	1	1	1
Bank Cushion	1	1	1	1	1	1	1	1
	39	39	47	52	37	37	44	44

HAZARD RATING: Highly hazardous = 5; Very hazardous = 4; Hazardous = 3; Not very hazardous = 2; Not hazardous = 1; and Unknown = 0.

FIGURE VI-20. SUBJECTIVE HAZARD RATINGS GULF OF MEXICO TO SAFETY ZONE

to October hurricane season. (See appendix F for a discussion of the destructive force of hurricanes and their effect on vessel navigation.)

Although currents have been the cause of a number of vessel casualties in the Gulf of Mexico, many have been due to the failure to consider currents in maneuvering, resulting in collisions and rammings. The hazardous rating assigned currents in figure VI-19 is due to the Florida Current which forces westbound vessels to come close to the Florida Keys to avoid the full force of that current.

The danger of grounding is more likely for westbound vessels in the Straits of Florida since they are closer to the shore than those which are eastbound. In a similar manner, eastbound vessels have less restricted maneuvering room than those which are westbound albeit the latter's restriction is self-imposed. These considerations are the reason for the variation in hazard rating shown in the "Restricted Maneuvering Room" item in figure VI-19 for the Straits of Florida, as well as the "Depth Less Than Charted" item.

The highly hazardous ratings in figure VI-20 given to offshore rigs in the Gulf of Mexico and safety fairways is due primarly to the presence of oil structures far out to sea and the permissive nature of the safety fairways which allows vessels to take "short cuts" through these hazards. This has also led to the highly hazardous rating for shoals in the SEADOCK safety fairway since a course direct from Dry Tortugas to the SEADOCK traffic separation scheme goes directly through Flower Garden Bank, a danger to VLCC operations.

Floating debris is present in all navigable waters, and partially submerged derelicts are not uncommon as can be seen from regular reports in Weekly and Local Notices to Mariners. This is reflected throughout figures VI-19 and VI-20 by hazardous ratings; the traffic separation schemes and safety zones, however, will be under constant surveillance by DWP authorities and this hazard should, therefore, not exist. This latter consideration has, therefore, been shown in figure VI-20 by a not hazardous rating.

As a further comparison, figure VI-21 shows essentially the same information as figures VI-19 and VI-20, but including Juaymah, substituting the Persian Gulf transit for the Gulf of Mexico transit, and excluding the Straits of Florida transit, since this latter body of water seems to have no counterpart in the Persian Gulf approach. The main differences in this matrix are reflected in the absence of tropical cyclones, the strong currents, the absence of information concerning the reliability and adequacy of aids to navigation in the Persian Gulf, the

Figure VI-18B
EXTERNAL HAZARD

EXTERNAL HAZARD	Gulf of Mexico Transit		Persian Gulf Transit	Safety Fairway (including "short cuts")			Traffic Separation Scheme			DWP Safety Zone		
	LOOP	Seadock	Juaymah	LOOP	Seadock	Juaymah	LOOP	Seadock	Juaymah	LOOP	Seadock	Juaymah
Structures, vessels, etc.						None Exists						
Floating debris, or submerged objects	3	3	3	3	3	—	1	1	2	1	1	1
Fixed objects—piers, bridges	1	1	1	1	1	—	1	1	1	1	1	1
Offshore rigs	5	5	5	5	5	—	1	1	1	2	2	1
Single Point Moorings	1	1	1	1	1	—	1	1	1	2	2	2
Aids to navigation	1	1	1	1	1	—	2	2	2	1	1	1
Other vessels anchored or moored	1	1	1	1	1	—	1	1	1	3	3	3
Other vessels docking or undocking	1	1	1	1	1	—	1	1	1	3	3	3
Other vessels meeting	2	2	2	2	2	—	1	1	1	1	1	1
Other vessels crossing	2	2	2	2	2	—	2	2	2	2	2	2
Other vessels overtaking	1	1	1	2	2	—	1	1	1	1	1	1
Aids to Navigation												
Reliability	1	1	2	1	1	—	1	1	1	1	1	1
Adequacy	1	1	2	1	1	—	1	1	1	1	1	1
Environmental Weather												
Storms, heavy weather	5	5	1	5	5	—	5	5	1	5	5	1
Adverse weather	2	2	2	2	2	—	3	3	3	3	3	3
Low visibility	2	2	3	4	5	—	3	3	3	3	3	3
Restricted Maneuvering Room												
Channel	1	1	1	2	2	—	1	1	1	2	2	2
Congested area	1	1	3	2	2	—	1	1	1	2	2	2
Unusual Current												
Erratic	1	1	3	2	2	—	2	2	2	2	2	2
Strong current	1	1	3	1	1	—	2	2	2	2	2	2
Depth Less Than Charted												
Charts Erroneous	1	1	1	1	1	—	1	1	1	1	1	1
Area Shoaled/Silted	1	1	1	1	5	—	1	1	1	1	1	1
Position of Hazard Doubtful	1	1	1	3	3	—	1	1	1	1	1	1
Bottom and Bank Effect												
Sheer	1	1	1	1	1	—	1	1	1	1	1	1
Suction	1	1	1	1	1	—	1	1	1	1	1	1
Bank Cushion	1	1	1	1	1	—	1	1	1	1	1	1
	39	39	44	47	52		37	37	34	44	44	39

HAZARD RATING: Highly hazardous = 5; Very hazardous = 4; Hazardous = 3; Not very hazardous = 2; Not hazardous = 1; and Unknown = 0.

FIGURE VI-21. COMPARATIVE SUBJECTIVE HAZARD RATINGS, LOOP, SEADOCK, AND JUAYMAH

exceptionally heavy VLCC traffic due not only to Ras Tanura/Juaymah, but also the other oil ports in the Persian Gulf, and the presence of a wide separation of opposing vessel traffic using Juaymah. The fact that there is no safety fairway at Juaymah is somewhat misleading since there is an extensive widely separated traffic separation scheme which should be compared to both a short, alternating, one-way traffic separation scheme, and a permissive safety fairway at both LOOP and SEADOCK.

3. Jurisdictional Problems With Foreign Vessels

Section 2(a)(1), the Declaration of Policy of the "Deepwater Port Act of 1974" (PL 93-627 93rd Congress), specifies that the act applies to deepwater ports beyond the territorial limits of the United States. Section 19(a)(1) of that act states that deepwater ports licensed under this law do not possess the status of islands and have no territorial seas of their own. Under section 19(c), the licensee of a deepwater port is not permitted, except as a result of force majeure, to allow foreign flag vessels to utilize the deepwater port unless the foreign state involved, by specific agreement with the United States, recognizes the jurisdiction of the United States over the vessel and its personnel while the vessel is located within the safety zone, and the vessel has designated an agent in the United States for receipt of service of process in the event of any claim or legal proceeding resulting from activities of the vessel or its personnel while located within such safety zone.

From these provisions of the Deepwater Ports Act and from the legislative history of the act,[1] the Congress has recognized that adequate authority exists for the regulation of the construction and operation of deepwater port facilities within the territorial seas of the United States; the prime purpose of the act, therefore, is to regulate those beyond the territorial seas. Congress also recognized the lack of jurisdiction which would exist over foreign vessels using the deepwater port, and therefore addressed this problem in section 19 as previously discussed. What has not been addressed in the act, however, is the legality of the licensee or the U.S. Coast Guard to control other foreign vessels who, through either ignorance or design, pass through the safety zone of a U.S. deepwater port. Rules and regulations issued by the U.S. Coast Guard concerning the operation of deepwater ports have given superficial treatment to the problem by merely directing the licensee to refuse admittance to such vessels, and specifying that other vessels may

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1. U.S. House of Representatives Report No. 93-668, Deepwater Ports.

not call at a deepwater port unless clearance has been obtained from the deepwater port Vessel Traffic Supervisor.[1]

This lack of jurisdiction may never present any practical difficulties. It should, however, be recognized as a potential hazard and some guidance provided to both the deepwater port licensee and the local U.S. Coast Guard operational commander. Other than notification of this (or these) safety zone(s) to the Inter-Governmental Maritime Consultative Organization (IMCO) as precautionary areas in which ships must navigate with particular caution and within which the direction of traffic flow may be recommended and designation of SPM swinging spaces as "areas to be avoided," no other recommendation is made. Simply charging the licensee with excluding foreign vessels over which it clearly has no jurisdiction is not considered to be an appropriate solution. Further study should be given to the jurisdictional problems with foreign vessels in U.S. deepwater ports.

4. Fault Tree Analysis

a. Overview

The fault tree analysis described in this section addresses the risks associated with deepwater port transits. The geographical area encompassed includes the Gulf of Mexico entries/exits through the Straits of Florida and the Yucatan Channel, the Gulf transit, per se, and the entry/exit to the DWP. Transfer operations within the DWP are beyond the scope of this analysis, and are the subject of other studies.

The Gulf transits considered here include high seas as well as coastal passages. Only collisions, rammings, and groundings were considered in the analysis. These are the types of casualties that are most often related to navigational and personnel factors, which are the primary considerations of the deepwater port analysis. Other casualty types -- structural failures, breakdown, fires, explosions, etc., generally result from equipment failures, structural weakness, and other factors that are not directly related to navigation. The objective of this analysis was to identify the causes and contributing factors of navigational and personnel fault accidents.

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1. U.S. Coast Guard, Deepwater Ports Regulations on Licensing Procedures and Design Construction, Equipment and Operations Requirements; and Proposal On Site Evaluation, Title 33, Port 150 (Published Federal Register, Volume 40, No. 217, November 10, 1975).

To accomplish this, histories of a number of actual accidents were evaluated to provide insights into the overall nature of an accident. Comparison of fault tree approaches and the nature of actual accidents revealed three drawbacks in accurately modeling transit accidents. This is discussed in detail in subsection b, "Background," below.

To overcome these drawbacks, a modified fault tree approach was selected, with the modifications reflecting the on-going operational concerns of a passage. These include navigation and conning procedures which, if less than adequate, can lead immediately to an accident, or can result in the perpetuation of errors that later cause an accident. A detailed description of the development of this modified fault tree model is given in subsection c below.

The model itself actually consists of numerous inter-linked, individual trees. Each of the individual trees covers a specific set of contributing factors, with the "linkages" to other individual trees indicating the role of each given set in the cause of an accident. Once the model was sufficiently developed, "after-the-fact" trees from several, actual case histories were generated as a means of validating the model. Both the model itself and its validation are provided in appendices D and E.

Following development of the model, analysis revealed some patterns, or trends, that could have an impact on accident reduction. From this, it tentatively appears that certain factors may play a more significant role in marine accidents than has previously been considered. Details concerning these results, as well as plans for further utilization of the model, are given in subsection d below.

b. Background

Fault tree analyses have been conducted on many projects for a number of years, often with good results. However, for the DWP transit application, three drawbacks were found with available approaches. These drawbacks are somewhat related, and also create disadvantages at several levels.

First, there is the inherent tendency of most approaches to be either too simplistic or too complex. For instance, fault trees that devote only a single block or two to "human error" provide no details on the myriad causes of human error. At the other end of the spectrum, complex trees can be so difficult to interpret that they function as little more than an academic exercise.

Second, fault trees are "binary" in nature, in that something (a factor, an action, an event, etc.) either occurs or does not occur, is present

or absent, etc. The disadvantages associated with this stem from the fact that vessel passages involve dynamic conditions that will vary considerably between any two extremes, perhaps, without ever even reaching them.

Third, most fault tree approaches are either geared to handle limited or predefined time spans, or else time is not specifically considered. That is, fault trees, if they deal with time at all, generally do so in terms of the limited period during which a fault occurs. The disadvantages associated with this stem from the fact that a given marine accident can involve various time periods differing by several orders of magnitude. For instance, a navigation error may go undetected and cause no problem until hours or days later when the juxtaposition of this and other factors creates a critical situation. This critical situation, in turn, can end in a casualty or near-miss in a matter of a very few minutes.

To overcome these drawbacks and their associated disadvantages, a number of case histories of actual marine casualties were evaluated to gain insights into the "anatomy of an accident". Marine casualty reports by the U.S. Coast Guard and the National Transportation Safety Board provided excellent information in that the "Findings of Fact" sections of these reports generally give detailed information on the entire passage. While other reports, as well as descriptions of personal experiences were also evaluated, the former were relied on more extensively on the basis that testimony under oath should be the most reliable.

The "anatomy of an accident," with respect to collisions, rammings, and groundings that evolved from this evaluation, has five primary characteristics. First, until immediately prior to the accident, the passage in all likelihood will have been a routine one. Any problems that might have occurred, such as equipment that required corrective maintenance, will have been viewed as "routine" in that such occurrences are regularly encountered and handled without further incidents at sea. Similarly, heavy weather, if encountered, will not necessarily be viewed as "non routine" but rather as a fact of life at sea.

Second, the immediate conditions that precipitate the accident usually occur suddenly and without warning. This may occur because if the conditions had developed more slowly or had given some warning, actions would be taken that would prevent the accident.

Third, a vast majority of accidents are caused by some combination of two or more causes or contributing factors. These causes and contributing factors generally do not appear to be related to any known, prior

problem. Further, it appears that the occurrence of only one cause or contributing factor is generally tolerated without any further, major incidents.

Fourth, the contributing factors or initial causes often occur on the order of hours before the accident or even as early as the beginning of the passage. (For instance, the vessel sails with out-of-date charts.) These can be termed "long-time-frame" factors, as opposed to the "short-time-frame" factors that occur immediately prior to an accident. These long-time-frame factors can accumulate or combine with other factors to increase the ultimate likelihood of an accident, or they can be corrected.

And fifth, there appear to be very few cases where the personnel involved in an accident were non-qualified or lacking in experience. In cases where an individual was cited as negligent, he was usually properly licensed and had years of applicable experience. Likewise, most of the vessels involved were properly certified and inspected.

As indicated above, the "anatomy of an accident" applies to collisions, rammings, and groundings. It is entirely possible that a different one would apply for fires, structural failures, mechanical breakdowns, etc. For this latter type accident, poor maintenance would play a larger role. Also, the data on which the above "anatomy of an accident" is based, chiefly involved U.S. vessels or vessels operating in waters under U.S. jurisdiction. While some differences could be expected from foreign vessels in non-U.S. waters, it appears that the broad outlines given above would still apply.

c. <u>Fault Tree Development</u>

After comparing the "anatomy of an accident" with available analytical techniques, it was concluded that a modified fault tree approach could provide a realistic model. The modifications necessary to the standard fault tree approach are as follows:

(1) Inclusion of time considerations to account for "short-time-frame" immediate accident causes, and "long-time-frame" contributing factors.

(2) Provisions to account for the "non-binary" nature of many causes and contributing factors.

(3) Provisions for grouping such that all conceivable categories of causes/contributing factors could be included without resulting in unwieldy over-complexity.

With respect to item (1) above, time considerations were laid out conceptually as shown in figure VI-22. The "intermediate time frame" causes/contributing factors were included to provide an additional degree of realism. It can be seen from the figure that a rough "time flow", from bottom to top, although not a precise time frame sequence occurs. This "time flow" was handled in the fault tree essentially as shown in figure VI-22 by structuring the fault tree parallel to the time flow.

With respect to item (2) above, the "non-binary" nature of many causes and contributing factors was found similar to those dealt with in nuclear applications through the MORT[1] approach. Thus, as is done with MORT, conditions were identified as "less than adequate" (LTA).

With respect to item (3) above, categories were first established, and cause/contributing factors assigned to them on a "cut and try", then refine, basis. It was found, for instance, that a "navigation" category led to unwieldy assignments that were neither indicative of actual situations, per se, nor informative as to relationships. Thus, the "elements" of navigation, i.e., fix-taking, assessment of line-of-position (LOP), assessment of approach angle, etc., were "tried" as categories, and found to provide good visibility of relationships while allowing logically consistent category assignments.

With the establishment of guidelines in these three areas, the development of fault trees was a straightforward process. Three levels of trees were generated, with the "top level" tree essentially paralleling figure VI-22 and with second and third level trees for the contributing factors.

The top level fault tree depicting the DWP entry/exit scenario is shown in figure VI-22. The second level trees and the itemized lists providing the third level trees are given in appendix D. In addition, to validate the fault trees, a sample of actual case histories were tested on the above trees and this is provided in appendix E.

d. Results and Applications

By evaluation of the fault tree paths and linkages, certain insights into why accidents happen, or do not happen, can be gained. This evaluation has been done qualitatively. The analysis indicates many causes associated with the

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1. W. G. Johnson, MORT: The Management Oversight and Risk Tree, prepared for the Atomic Energy Commission, February 12, 1973.

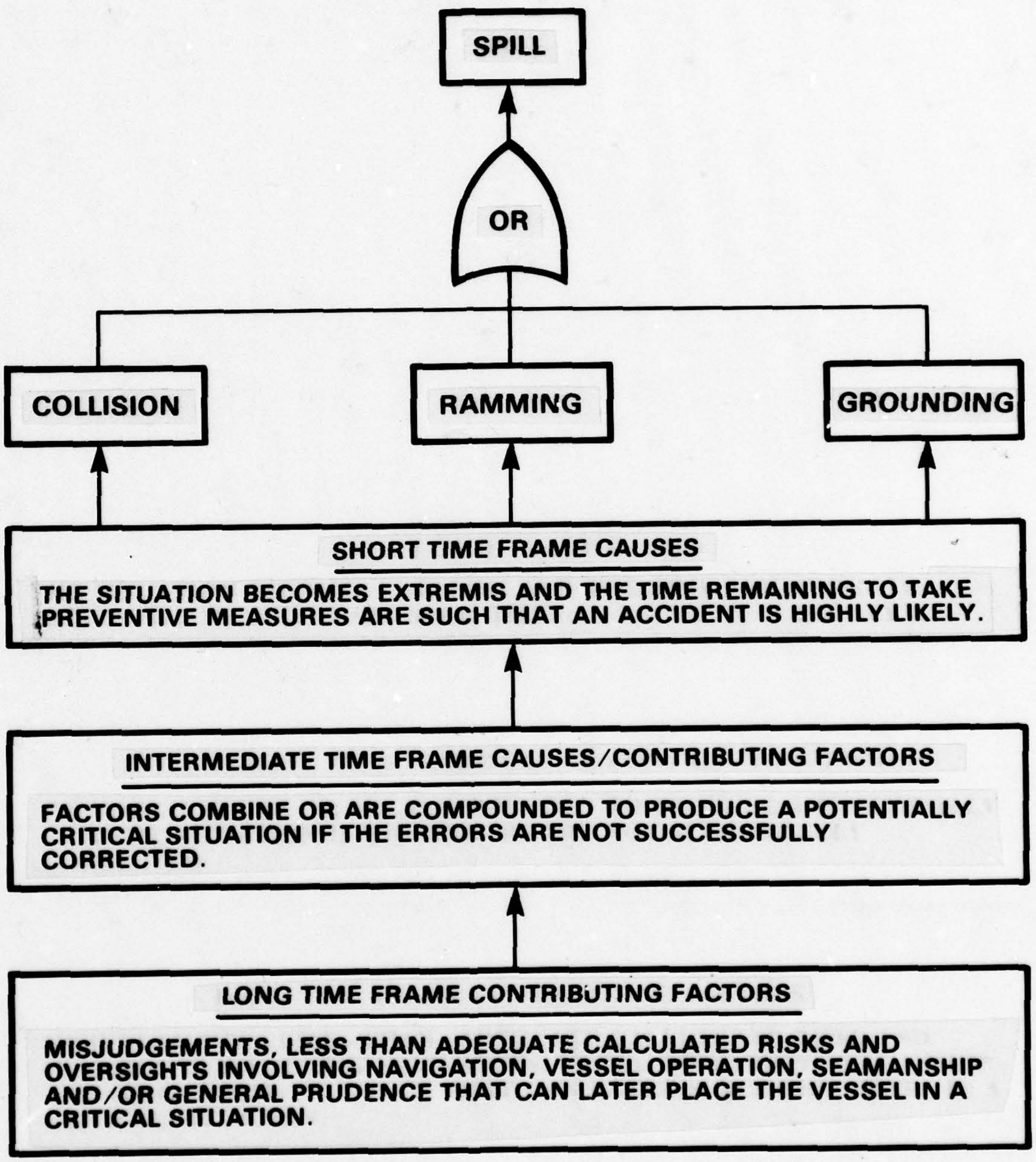


FIGURE VI-22. CONCEPTUAL RELATIONSHIPS OF FAULT TREE TIME CONSIDERATIONS

lower level contributing factors. Some of these factors are due to such things as calculated risk, lack of skills or even negligence, but a large number are associated with commonly applied but imprecise navigation and conning policies and procedures. As noted with regard to the "anatomy of an accident", more than one contributing factor seems required for a critical condition to develop, but with the multitude of possibilities, most of them in "OR" gate relationships, it would seem that potentially critical conditions are more likely than not.

If this is the case, it appears some process of detecting and correcting the conditions must occur or else there would be far more accidents than there are now. This would logically be via the "early action" block of the top level fault tree (figure VI-23), yet there is little available information on how this occurs. As can be seen from the detailed subtree for this "early action" block (figure D-4 in appendix D), many judgmental factors are involved, e.g., situation incorrectly reassessed, re-assessment correct but selected action LTA, etc. These, in turn, can be due to "hard" errors (incorrect radar reading, for instance) or "soft" errors (inadequate communication at change of watch, for example).

A major implication of this on DWP transit risks is that with VLCC's, if the early action is less than adequate, there seems little hope of avoiding an accident. That is, once a VLCC becomes in extremis, the avoidance action, as shown in the subtree in figure D-5 in appendix D, is highly likely to be less than adequate due to maneuvering characteristics.

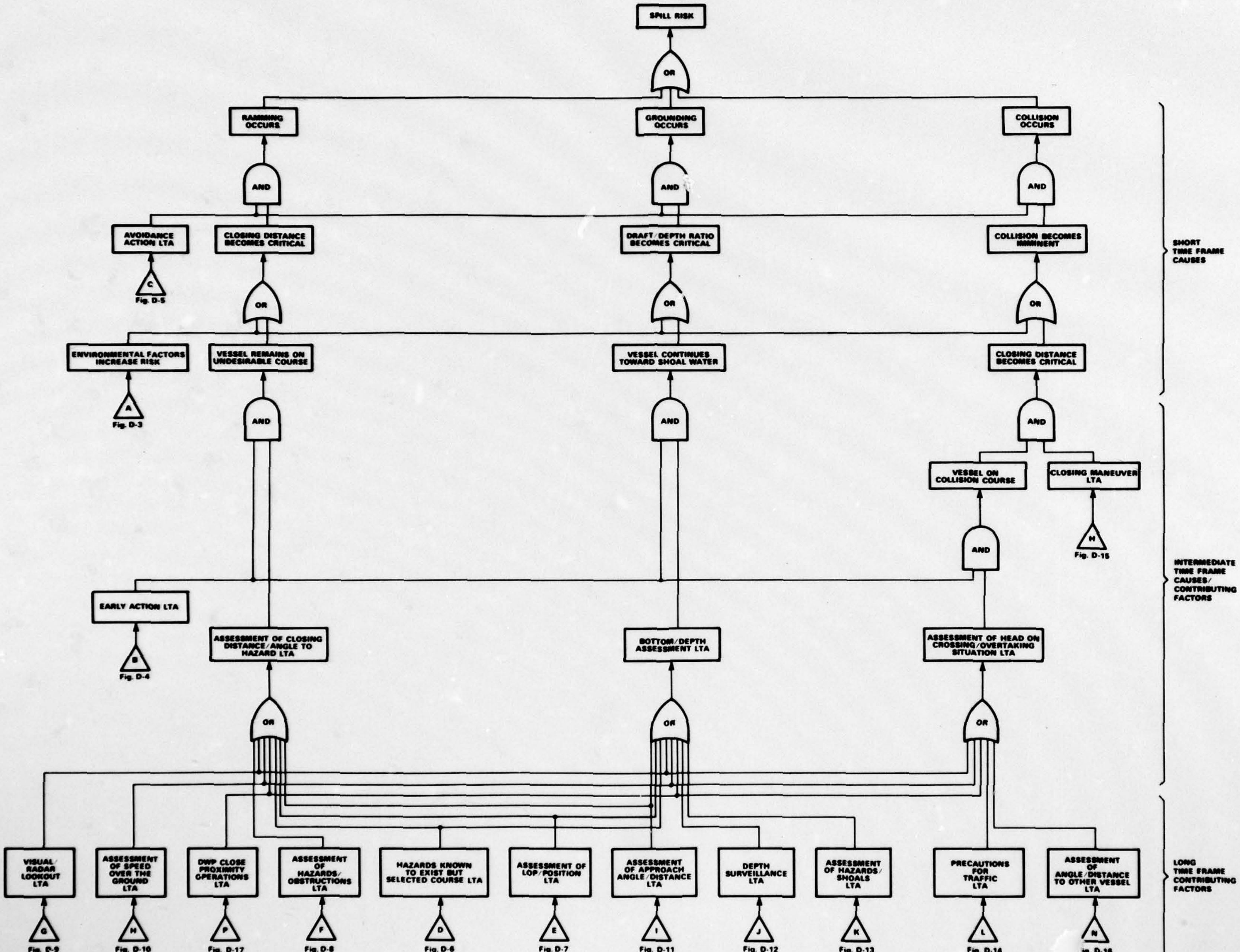
Risk mitigation measures have traditionally been applied and, indeed, been thought most applicable at the lowest level of the contributing factors (better training, improved navaid coverage, etc.). If the above observations from the fault tree are correct, they suggest that the most effective risk mitigation measures would be those that dealt with the "early action" category. That is, if these "early actions" are now operating to detect and correct errors, then improving them could prove even more productive.

This is not meant to discourage in any way the traditional approach of applying mitigating measures at the lower contributing factor levels. With currently available data, this approach is the only one that provides any degree of measurable criteria.

The fault trees could prove useful in the evaluation potential mitigating measures for personnel related activities as well as for improved systems. Since the fault trees cover NAVAIDS, navigation documentation/informa-

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE

FIGURE VI-23. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE



tion (e.g., Local Notices to Mariners, Coast Pilot, etc.), meteorological information dissemination, vessel operation procedures, and other pertinent navigation/conning aspects, the factors related to such areas can be evaluated in terms of the impacts the mitigating measure might have.

Somewhat related to this use in evaluating mitigating measures is the potential application of the fault trees in planning considerations. The scope of this application would go beyond that of strict evaluation of mitigating measures in that the fault trees could provide the means for checking for oversights. They could also provide the means for determining if the plans under consideration increased risks by increasing the chances that some less than adequate situation would occur.

Another application that could prove quite beneficial involves the use of the fault trees as a training aid. They were developed to depict "what causes marine accidents," and it seems axiomatic that the more one knows about what causes accidents, the more he will know about how to prevent them. This application could involve use of the fault trees as a tool for increasing "awareness."

An application of the fault trees that could have far reaching benefits would be their use in accident investigations and reporting. In numerous places throughout this report, the lack of specific, detailed data on marine casualties has been cited. The data bases that have been compiled to date have necessarily had limited objectives. However, analysis of marine systems now involves a number of rapidly maturing disciplines with more sophisticated needs for specific, detailed data. The causes and contributing factors of the fault trees, together with their relationships and structure, could provide a realistic model for accident investigation and reporting.

e. Utilization of VCRS Data For Fault Tree Quantification

The objective of the fault tree analysis (see appendix D) was to identify the causes and contributing factors of navigational and personnel fault accidents associated with deepwater port transits. This analysis was not bound by any data constraints and therefore was able to provide qualitative insights to the entire hazard scenario and its causal effects on deepwater port activities.

In order to provide a more quantifiable meaning to this causal tree, the VCRS data file was reviewed so that primary and contributing factors recorded could be used to explain the hazards associated with vessel operations. This was done with the knowledge that the causal data did not represent

DWP operations but with the understanding that basic shipboard activities would be similar regardless of destination (use of radar). The sparseness of the VCRS data file for use in quantifying the fault tree analysis became quickly apparent and was not pursued. However, some important and interesting results were obtained from this statistical analysis.

The hierarchy of primary causes and contributing factors ascribed to tanker casualties are presented in appendix G.

B. Hazard Ranking

The hazard ranking scheme presented in this section is primarily based upon two information sources: vessel casualty data and the subjective analysis of deepwater port transits presented in part A of this section. These sources are treated separately to develop two distinct sets of hazard rankings by transit zone. The casualty data have the advantage of yielding quantitative results in terms of relative frequencies of citation for each hazard. However, the data are limited in terms of direct application to the deepwater port situation. On the other hand, the subjective analysis provides specificity in terms of the scenario but data are based on qualitative rather than quantitative information. Therefore, the two rankings were combined to yield a composite hazard ranking, which represents an estimate of the relative criticality of the primary potential hazards to deepwater port navigation from the Straits of Florida or the Yucatan Channel to the safety zone.

1. Ranking by Vessel Casualty Data

The primary data sources for ranking the hazards are the Vessel Casualty Reporting System (VCRS) and the Tanker Casualty File. The VCRS, discussed in Section IV, includes data on accident causes and contributing factors. Generally, the causes and factors can be divided into four categories:

- Personnel Fault

  Rules of the road violation

  Improper lookout

  Misjudged effects--wind, current, speed

  Failure to ascertain position

  Failure to utilize available navigation equipment

  Carelessness/inattention

  Improper corrective procedures

  Failure to determine height of tides

  Calculated risk

- Equipment or Structural Failure

  Normal wear

  Material fault

Design error

Operating personnel error

- Natural Conditions

  Heavy or adverse weather--typhoon, hurricane, gale force winds, small craft warnings, large swell

  Low visibility

  Erratic or strong currents

  Sheer, suction, bank cushion

  Depth less than charted--erroneous charts, area shoaled/silted, position doubtful

- Man-made Conditions

  Congested area--restricted maneuvering

  Channel--restricted maneuvering

  Floating debris or submerged object

  Structures--offshore oil rigs, piers, bridges, etc.

  Anchored or moored vessels

In addition to these factors, the VCRS identification of casualty types implicitly include certain types of hazards, particularly for rammings and collisions. The collision and ramming categories are:

- Collision with vessel, meeting situation
- Collision with vessel, crossing situation
- Collision with vessel, overtaking situation
- Collision with vessel anchored or moored
- Collision with vessel while docking or undocking
- Collision with vessel in fog
- Collision with vessel, not otherwise classified
- Collision with floating or submerged objects

- o Collision with fixed objects--piers, bridges, etc.
- o Collision with ice or ice fields
- o Collision with aids to navigation
- o Collision with offshore rigs, seaplanes, etc.

The primary objective of hazard identification and ranking is to provide an ordered set of data against which to assess risk mitigative measures. Most of the measures of concern to this study relate to improvement of ship navigation (in the broadest sense) including personnel manning, qualifications, and training. Therefore, the hazards of interest are those that affect navigation, from either the external sources--natural or man-made conditions--or personnel actions. Equipment or structural failures are excluded as primary causes or factors, although structural failure and breakdown as types of casualties resulting from other causes such as heavy weather are included.

The ranking of hazards is done by transit zones: straits and channels, open sea, safety fairway, traffic separation scheme, and safety zone. Because no data explicitly exist for such categories, surrogates are used based upon location types from the Tanker Casualty File. The surrogates are those used in the oil spill prediction discussed in Section V. The zones and their surrogates are:

Straits and channels - coastal

Gulf of Mexico - open sea

Safety fairway and traffic separation scheme (TSS)--harbor entrance

Safety zone - harbor (piers excluded)

Groundings are excluded from consideration for the safety fairway, TSS, and safety zone because of the depths involved, as explained in Section V.

The VCRS location information does not allow categorization into location types as does the Tanker Casualty File (TCF), while the latter does not contain causality information, from which hazards can be determined. Therefore, these two files were combined to develop hazard data by zone. A total of 97 casualties involving tankers during the period covered by the TCF, 1969-1973, were used to develop the hazard list. The casualties involved U.S. registered tankers of sizes ranging from 500 to 120,000 DWT. The casualties occurred throughout the world, with about 75 percent in U.S. waters.

Table VI-1 summarizes the casualty data used in the ranking scheme in terms of location and casualty type. The breakdown of hazards is presented by zone in

Table VI-1 Summary of Tanker Casualties Used for Hazard Ranking

	Number of Casualties				
Casualty Type	Coastal	Open Sea	Harbor Entrance	Harbor	Total
Collisions	6		7	26	39
Rammings	6	1		11	18
Groundings	8		*	*	8
Explosions	1	1	1	1	4
Fires		2		2	4
Structural Failures		7		1	8
Breakdowns	5	8		3	16
Total	26	19	8	44	97

* Groundings excluded

Data Base: Casualties for U.S. registered tankers 1969-1973 recorded in both the Tanker Casualty File and the Vessel Casualty Reporting System

Table VI-2, along with the hazard criticality indices and ratings, which are explained below. The hazards are taken from the VCRS casualty type definitions and the causal and contributing factors specified in the VCRS. For example, collision with a vessel, in a meeting, crossing, or overtaking situation (VCRS casualty type definitions) is interpreted as implying a hazard of vessel traffic. Similarly, collision with an offshore rig is interpreted as the offshore rigs being a hazard and grounding implies depth as a hazard. A casualty may involve more than one hazard. For example, a collision with a vessel in fog due to improper use of navigational equipment would imply three hazards: vessel traffic, low visibility, and pesonnel fault. Some casualties result from causes not on the hazard list such as equipment failure or fault of other vessel. These are included in the category "other" in Table VI-2 at a rate of one hazard citation for each casualty where causes are not in one the hazard categories listed. For example, in the coastal zone only 20 of 26 casualties were due to any of the hazards listed. The remaining six were due to equipment failures or fault of other vessel. For harbor entrance and harbor locations, groundings were excluded as noted above.

To aid in ranking the hazards within and among the zones, a measure of relative criticality of each hazard for each zone was developed. This measure, termed the criticality index, reflects the equivalent numbers of casualties ascribed to each hazard. This can be expressed as follows:

$$I_{ij} = H_{ij} \frac{C_i}{H_i}$$

where:

I_{ij} = criticality index for hazard j in zone i

H_{ij} = number of times hazard j was cited in zone i

C_i = number of casualties in zone i from which the hazard data were derived

H_i = total number of citations of hazards for the C_i casualties

The value of H_i is greater than or equal to C_i since each casualty is ascribed to at least one hazard. The ratio C_i/H_i represents the average number of casualties per hazard citation in the zone. In other words, it implies that H_i/C_i hazards on the average were involved in each casualty. Therefore, each occurrence of hazard j in zone i contributes to a portion of a casualty; that is, to C_i/H_i of a casualty. For example, if the

Table VI-2 Frequencies of Citation for Hazards from Casualty Data

	Surrogate Location Type (Transit Zone)											
	Coastal (Straits and Channels)			Open Sea (Open Gulf)			Harbor Entrance (Safety Fairway and TSS)			Harbor (Safety Zone)		
Hazard	Citations	Criticality Index	Rating	Citations	Criticality Index	Rating	Citations	Criticality Index	Rating	Citation	Criticality Index	Rating
Debris, submerged object	5	3.3	3	1	1.0	2				3	1.5	2
Fixed object										5	2.4	3
Nav aid - ramming										2	1.0	2
Vessel traffic	5	3.3	3				2	0.8	2	10	4.8	4
Vessels docking or undocking							1	0.4	2			
Vessels moored or anchored							1	0.4	2	13	6.3	5
Nav aid - adequacy	1	0.7	2							2	1.0	2
Adverse or heavy weather	2	1.3	2	5	5.0	5				6	2.9	3
Low visibility							4	1.6	2	3	1.5	2
Restricted channel	5	3.3	3				5	2.0	3	6	2.9	3
Congested area							1	0.4	2	8	3.9	4
Unusual currents										10	4.8	4
Depth	8	5.3	5				*			*		
Personnel fault	7	4.7	4				4	1.6	2	18	8.7	5
Other	6			13			1			5		
Total hazard citations	26			19			8			44		
Total casualties	39			19			20			91		

* groundings not included

229 230

average in a zone is 2 hazards per casualty each citation of a hazard represents an equivalent of one-half a casualty. Thus for adverse weather in the harbor zone indicated in Table IV-2 results in an index value of 3 "equivalent" casualties. This measure provides a means to rate hazards within and among zones on an equitable basis, so that a hazard criticality index value in one zone can be directly compared with a value in another zone. Because of the nature of the casualties in the different zones, the ratios of hazard citations to casualties differ significantly. In the open sea the ratio is one because, as seen in Table VI-1, most casualties are of nonimpact natures, which are generally single cause casualties. In more congested and restricted areas such as harbors, harbor entrances, and coastal waters, most casualties are impact types (collisions, rammings, groundings) which generally involve several causal factors. The hazard criticality indices are included in Table VI-2.

In order to allow comparison of the results of the hazard data analysis with the subjective ratings given in Figures VI-19 and VI-20, a comparable rating measure was developed from the criticality index. The two rankings were then combined to yield a composite hazard ranking, will be shown.

Ranges of values of the criticality index were equated with hazard ratings in terms of integers from 1 to 5. Hazards with the highest index values were assigned 5's, interpreted as in the subjective rating scheme as "highly hazardous." Any hazard that was cited in the data was considered significant enough to be assigned a rating of at least 2, "not very hazardous." Those that were not cited were considered as "not hazardous," or a rating of 1. The rating values were assigned by equating index numbers above 5.0 with a rating of 5 and dividing the range from 0.4 (the lowest index value) to 5.0 into approximately equal intervals, as follows:

Criticality Index Range	Hazard Rating	Interpretation
≥ 5	5	Highly hazardous
3.5 - 4.9	4	Very hazardous
2.0 - 3.4	3	Hazardous
0.4 - 1.9	2	Not very hazardous
< 0.4	1	Not hazardous

The ratings for the hazards are shown in Table VI-2.

The resulting hazard rankings based on the casualty data are presented in Table VI-3. Other measures were considered for the rankings including use of a measure reflecting the severities for the casualties in addition to the casualty frequencies. Oil spillage would probably have been most useful for this purpose; however, only 11 of the 97 tankers casualties analyzed for the hazard resulted in oil spills. Another possible measure, the level of damage (dollar values), is recorded in the VCRS for each casualty. However, examination indicated that many of these seem extremely low. For example, three crossing collisions occurring in coastal areas resulted in a total of only $1,000 damage, according to the data file. Further, very few casualty reports indicated deaths, injuries, cargo damage or property damage other than to the vessel. Because none of these data were considered to adequately reflect accident severity, only the casualty frequencies were used in the ranking scheme.

2. Auxiliary Casualty Information

To augment the data presented in table VI-2, hazard citations involving vessels greater than 5,000 GT occurring in the Gulf of Mexico were summarized by causal factors, as listed in table VI-4. These 135 hazard citations gleaned from 148 casualties recorded in the VCRS from 1969 to 1977, occurred in the Ocean Gulf areas, which excludes waters covered by Inland Rules of Navigation. Thus, they reflect coastal and open sea conditions and exclude harbors and, generally, harbor entrances. All types of vessels--primarily tankers and cargo ships--are included in the data base. This set of data differs from the data used in the hazard ranking in that the latter, which have no geographic or size constraints, include only casualties common to the VCRS and TCF files. The data indicate that personnel fault is the predominant causal factor in the Gulf with restricted channels and heavy or adverse weather next. Floating debris and submerged objects also represent significant hazards.

Figure VI-24 shows the geographic casualty patterns for tankers for the years 1969 to 1977 taken from VCRS files. These data include casualties of tankers larger than 5,000 GT occurring in the Gulf of Mexico, excluding waters covered by the Inland Rules of Navigation. The 51 casualties shown include 10 groundings, 7 collisions, 6 rammings, 23 breakdowns, 2 structural failures, 1 explosion, 1 fire, and 1 classified as other, which was fracture of a ballast pump while deballasting. The groundings were primarily concentrated in the Sabine Pass area. The 6 rammings involved 2 oil drilling platforms, 2 submerged objects, 1 buoy and 1 tug towline. In addition, 6 of the 23 breakdowns involved propellor damage which were generally attributed to floating debris. These data represent a subset (tankers only) of the data summarized in table IV-4.

Table VI-3 Hazard Rankings Based on Casualty Data

(Straits and Channels) Coastal		Open Gulf (Open Sea)		Fairway and TSS (Harbor Entrance)		Safety Zone (Harbor)	
Depth	5	Weather	5	Restricted Channel	3	Personnel fault	5
Personnel Fault	4	Debris	2	Personnel Fault	2	Moored Vessels	5
Restricted Channel	3			Low Visibility	2	Congested Area	4
Traffic	3			Anchored Vessels	2	Currents	4
Debris	3			Vessels docking/ undocking	2	Traffic	4
Weather	2			Congested Area	2	Weather	3
Nav aid - adequacy	2			Traffic	2	Restricted Channel	3
						Fixed Objects	3
						Visibility	2
						Nav aid - adequacy	2
						Debris	2
						Nav aid - ramming	2

Code: 5 = highly hazardous, 4 = very hazardous, 3 = hazardous, 2 = not very hazardous

233

Table VI-4 Vessel Casualties in Gulf of Mexico, 1969-1977

Hazard	Number of Hazard Citations							
	Collision	Ramming	Grounding	Explosion Fire	Structural Failure/Breakdown	Other	Total	Percentage
Floating debris/ submerged object		9			1		10	7
Fixed object		4					4	3
Offshore rig		4					4	3
Nav aid - ramming		4					4	3
Other vessel anchored or moored		1					1	1
Traffic		11					11	8
Not otherwise classified		1					1	1
Heavy or adverse weather	3	3		1	6	2	15	11
Low visibility	3	2					5	4
Restricted channel		5	12				17	13
Congested area		1				1	2	1
Currents			8				8	6
Area shoaled			6				6	4
Depth less than charted			7				7	5
Erroneous charts			1				1	1
Personnel fault	10	9	16	3	1		39	29
Total Citations	16	54	50	4	8	3	135	100

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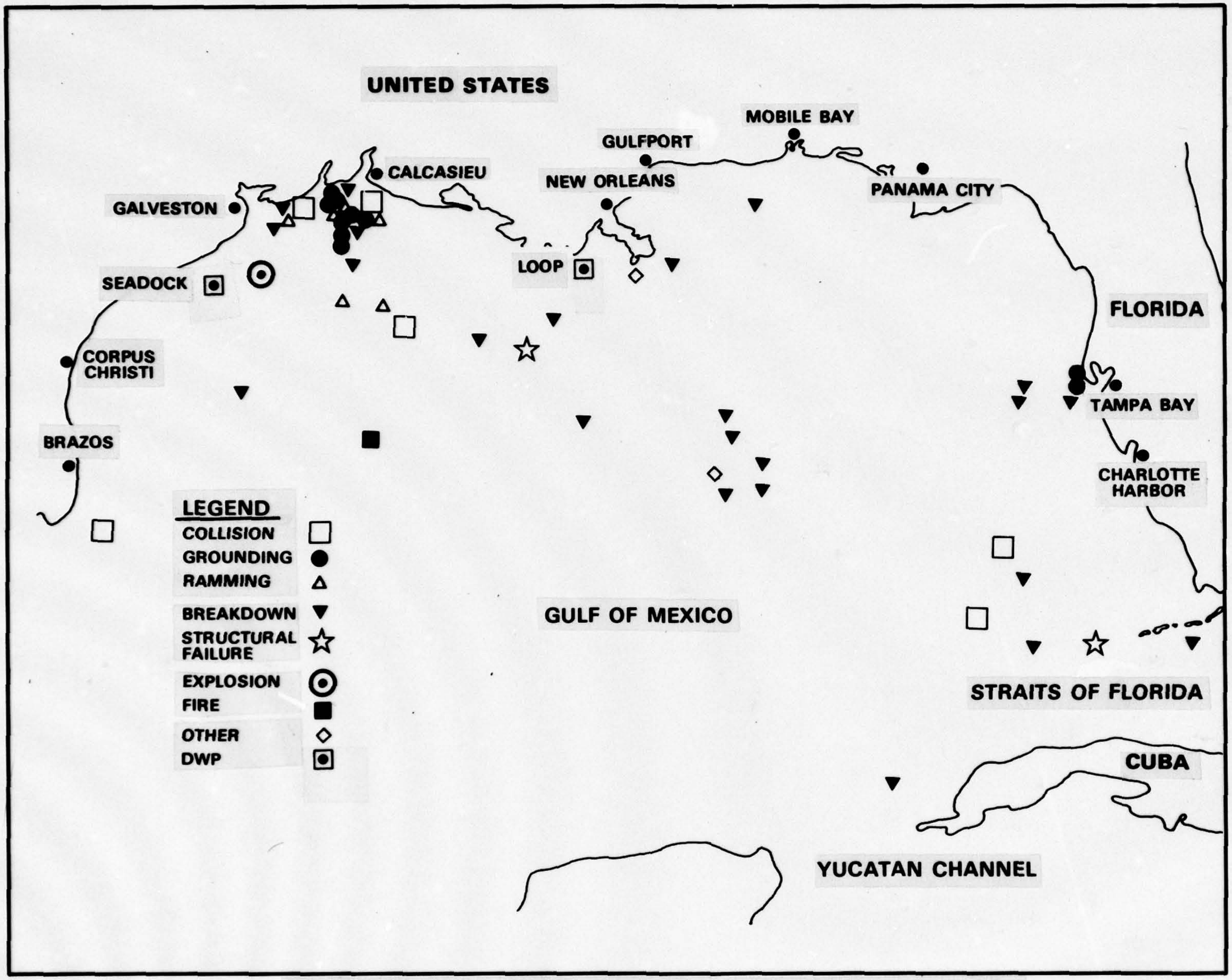

FIGURE VI-24. VESSEL CASUALTIES—CAUSE AND LOCATION

3. Subjective Hazard Ranking

Since the hazard rankings of table VI-3 are based on surrogates to the deepwater port transit zones, they require some modifications to account for peculiarities of the deepwater port transit operations. For example, no casualties involving ramming of offshore oil rigs were included in the data used in the ranking. However, they clearly could present a hazard to navigation in the regions of the deepwater ports, if vessels do not restrict themselves to the safety fairways. Indeed, there have been several instances of ships ramming oil rigs in the Gulf, including two of the rammings shown on figure VI-24.

Because of these considerations and because of the sparseness of the data, the subjective ratings of hazards given in tables VI-19 and VI-20, based on the paper and actual transits, are used to reorder the rankings of table VI-3.

Table VI-5 presents the subjective rankings and average values of the ratings for each of the five transit zones. The averages are determined over both ports and over the six routes through the Straits of Florida. Personnel fault is not included in the list since the paper and actual transits were concerned only with external hazards.

4. Composite Hazard Ranking

The hazard rankings based on the causalty data (table VI-3) and the subjective rankings upon the actual and paper transits (table VI-5) were combined to obtain a composite hazard ranking as shown in table VI-6. Factors considered "not hazardous" (rating = 1) are not included in the table. In addition to two hazard rankings, the information of figure VI-24 and table VI-4, although not location specific, were considered in developing the composite rankings, as discussed below.

It should be emphasized that the terms "highly hazardous," "very hazardous," etc., are relative. A factor judged as being potentially hazardous might impact an extremely small portion of the vessels traversing the area that it affects. This can be seen from the overall historical vessel casualty rate, which was shown in Section IV to be less than 1 casualty per 1,000 port calls. (As discussed in Section V, the predicted DWP rate is significantly less than this historical rate.) The hazard rating terms reflect only the relative importance of each hazard category within the set of hazards causing or contributing to vessel casualties.

The rationale for developing the composite hazard rankings from the two ranking schemes is discussed by transit zone below.

Table VI-5 Subjective Hazard Rankings

Straits and Channels		Gulf		Safety Fairway		Traffic Separation Scheme		Safety Zone	
Weather	5	Weather	5	Weather	5	Weather	5	Weather	5
Congested area	4	Offshore rigs	5	Offshore rigs	5	Low visibility	3	Low visibility	3
Vessel traffic	4	Debris	3	Low visibility	4	Vessel traffic	2	Moored vessels	3
Debris	3	Low visibility	2	Depth	3	Currents	2	Offshore rigs	2
Low visibility	2	Vessel traffic	2	Debris	3			SPMs	2
Depth	2			Vessel traffic	2			Vessel traffic	2
Anchored vessels	2			Congested area	2			Currents	2
Currents	2			Currents	2			Congested area	2
Restricted channel	2								

Code: 5 = highly hazardous, 4 = very hazardous, 3 = hazardous, 2 = not very hazardous

Table VI-6 Composite Hazard Ranking

Straits and Channels		Open Gulf		Safety Fairway		Traffic Separation Scheme		Safety Zone	
Personnel fault	4	Weather	5	Weather	3	Weather	3	Personnel Fault	5
Weather	4	Offshore rigs	3	Offshore rigs	3	Low visibility	3	Weather	5
Vessel traffic	3	Debris	3	Low visibility	3	Personnel fault	2	Low visibility	3
Debris	3			Debris	3	Vessel traffic	2	Moored vessels	3
Depth	2			Personnel fault	2			Currents	2
Low visibility	2			Vessel traffic	2			Vessel traffic	2
Anchored vessels	2			Depth	2			Offshore rigs	2
Currents	2							SPMs	2
Restricted space	2								

Code: 5 = highly hazardous, 4 = very hazardous, 3 = hazardous, 2 = not very hazardous

a. Hazards in the Straits and Channels

Personnel fault, not included in the subjective ranking, is indicated as "very hazardous" (R = 4) in the casualty data analysis. Since the vessel operations in the straits are not significantly different from transit operations in most coastal waters involving vessel traffic, and possible shallow depths, personnel fault is ranked high for straits and channels in the composite ranking. Further delineation and discussion of personnel fault as a factor in tanker operations is presented in appendix H.

Adverse or heavy weather rated high in the subjective ranking, for the straits with a rating of 5, and lower in the casualty data ranking, with a rating of 2. However, weather is indicated as a significant factor in vessel casualties occurring in the Gulf, as shown in table VI-4. Weather was therefore assigned a rating of 4 for the straits and channels because the Gulf-specific casualty data and analysis of weather in the Gulf (section IV.D) indicates this could be a significant hazard.

Vessel traffic is rated as a 3 from the casualty data and a 4 in the subjective rating. It is not expected that the traffic through the Straits of Florida and Yucatan Channel will be any more dense than as most U.S. coastal areas. Therefore, the composite rating for vessel traffic is 3. Congested areas as a hazard was combined with vessel traffic in the composite ranking scheme.

Floating debris and submerged objects (termed "debris" in the tables) is assigned a rating of 3 since it is given this rating in both the casualty data and subjective ratings.

For the straits and channels depth was a significant hazard in the casualty data, based on coastal areas in general. However, for the Straits of Florida or the Yucatan Channel specifically, depth does not appear to present a significant hazard as indicated by a hazard rating of 2 in the subjective analysis. Further, the data of Figure IV-24 indicated no groundings in the area of the Straits of Florida. Therefore, a hazard rating of 2 was assigned to depth in the straits.

Restricted maneuvering room (restricted channel), which is indicated as a significant hazard for coastal areas in general, is not expected to represent a large problem in the straits. There are some maneuvering constraints in the Straits of Florida for westbound traffic, which sails close to shore, which is the reason for the rating of 2 assigned to this hazard in the composite ranking.

The remaining hazard included in the casualty data for this zone, navaid adequacy, occurred only once in straits and channels, resulting in a rating of 2. This

hazard was not rated as significant in the subjective ranking. Thus, it was assigned a rating of 1 in the composite ranking, resulting in ommission from the hazard list.

The hazards of low visibility, anchored or moored vessels, and unusual currents did not occur in the casualty data used in the hazard ranking. As shown in table VI-5, and discussed in subsection VI A, it was judged that these factors would present limited hazards in the straits. Thus, the subjective ratings of 2 for each were assigned in the composite rating.

b. Hazards in the Open Gulf

Only three of the hazard categories appear to be significant in the open Gulf area. Adverse or heavy weather is rated high in both rating schemes. Debris was a factor in only one of the 19 open sea casualties summarized in table VI-2. However, three of the structural failures occurring in the open Gulf, as shown in figure VI-24, were caused by floating debris or submerged objects. Further, 10 of the Gulf casualties summarized in table VI-4 involved floating debris or submerged objects. Debris was therefore assigned a rating of 3 for the open Gulf area.

Offshore rigs do not appear as hazards in the casualty data of table VI-2. However, for the Gulf waters, rigs clearly present a hazard; in fact, two of the rammings shown in figure IV-24 involved offshore rigs. Consequently, this hazard was assigned a rating of 3 for the open Gulf area.

Since low visibility and traffic did not appear as hazards in the open sea data, these factors were given a rating of 1 in the composite data.

c. Hazards in the Safety Fairway

Adverse or heavy weather is not indicated as a hazard in the vessel casualty data for harbor entrances. However, harbor entrances are generally more protected than the safety fairways, which will be in open sea. It is expected that storm warnings would cause many vessels to delay their approach to the ports, reducing the weather hazard in the fairways relative to the open Gulf. Thus, weather was assigned a rating of 3 in this zone.

Offshore rigs are rated the same in the safety fairway as in the open Gulf (3) because of the possibility of tankers taking shortcuts to the safety zones through regions populated by these rigs.

Low visibility was rated as a 4 in the subjective ratings for the safety fairway. However, the casualty data do not substantiate this high a rating. There were only four instances of low visibility as a causal factor in harbor entrances, resulting in a rating of

2. Further, the Gulf data of table VI-4 shows only five citations for low visibility, or four percent of the hazard citations recorded for these data. The composite rating assigned to low visibility was 3.

Even though floating debris/submerged objects do not appear as hazards in the harbor entrances casualty data it is expected to present the same hazard in the safety fairways as in the open Gulf. Consequently, this hazard was assigned a rating of 3.

Personnel fault is rated as a 2 for the safety fairway zone, based on the harbor entrance casualty data. Vessel traffic is rated at a level of 2 since it has this value in both the subjective and casualty data ratings. The hazard category of "congested area" is considered essentially equivalent to vessel traffic (the former is derived from casualty type definition and the latter from causal factors in the VCRS), and thus is not entered separately on the composite ranking list.

Depth is included as a hazard in the fairways because of the possibility of groundings on the Flower Garden Banks south of the Sabine Pass, as discussed in subsection VI-A. Vessels enroute to SEADOCK could encounter these banks if they do not follow the safety fairway. Grounding is not considered a significant possibility for LOOP or SEADOCK if the safety fairways are followed. Depth as a hazard does not appear in the casualty data summary for fairways because groundings were not considered in the general case. This hazard was assigned a rating of 2.

Unusual currents do not appear in the casualty data for harbor entrances. This hazard is cited in the Gulf data of table VI-6 only for groundings (8 casualties) which are not considered in the safety fairway (except for the Flower Garden Banks). Thus, currents were not considered a hazard in the safety fairway zones.

The fairways are not considered to be as restricted channels since there is freedom to sail outside the boundaries. They will tend to channelize traffic somewhat but this effect is implicit in the vessel traffic hazard.

Anchored vessels are not expected to occur in the area of the safety fairways. Therefore, this hazard was not included in the composite ranking.

d. Hazards in the Traffic Separation Scheme (TSS)

Weather, low visibility, personnel fault, and vessel traffic are considered to have the same relative contributions to vessel casualties in the TSS as in the safety fairway. Other hazards that are expected to obtain in the fairways, but not in the TSS, are offshore rigs, debris, and depth, based upon the subjective analysis of subsection VI-A.

e. Hazards in the Safety Zone

Personnel fault is rated high in the safety zone based upon the casualty data for harbors. Adverse weather does not predominate in the casualty data for harbors in table VI-2 because of the protected nature of harbors. However, since the safety zone is in open sea, it is expected that adverse weather would have more effect than in harbors. Further, because more exacting navigation is necessary in the limited confines of the safety zones, weather could have a greater effect than in the fairways or TSS.

Low visibility is rated as a 3 in the safety zone by the subjective analysis and a 2 based on the casualty data. Because of the exacting maneuvering required in the safety zone, low visibility could be significant. The composite rating assigned is 3.

Moored vessels could represent a hazard in the safety zone, although not as significant as in a typical harbor, which is generally more congested. Thus the rating of 3 assigned to this hazard by the subjective analysis is used in the composite rating rather than the casualty data rating of 5.

Similarly, traffic and currents are assigned the values given in the subjective rating scheme. Offshore rigs are considered a possible hazard if a vessel strays from the safety zone. The vessels could ram the single point moorings (SPMs), but generally if this occurs it is expected that the damage to the vessel would be slight. Thus a rating of 2 is assigned for SPMs.

Fixed objects and navigational aid adequacy and restricted channels do not appear to apply to the safety zone. Debris is not expected to represent a problem because these areas can be closely policed.

241

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249
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Appendix A

MONTE CARLO SIMULATION TO ESTIMATE TOTAL AMOUNT OF OIL SPILLED

The statistical distribution for total amount of oil spilled over a given period of time is given by:

$$v(x) = \sum_{n=o}^{\infty} p(n)f^{n*}(x) \qquad (1)$$

where:

$v(x)$ = probability density function for the amount spilled, x.

$p(n)$ = probability of n spills.

$f(x)$ = probability density function for spill size.

$f^{n*}(x)$ = n-fold convolution on f(x).

For this study, p(n) is a negative binomial distribution and f(x) a log normal distribution. The convolution of a log normal with itself does not yield a tractable solution; consequently, v(x) was evaluated by computer simulation of equation (1).

The simulation involves the following steps, as shown in flow diagram of table A-1:

- Generate n, the number of spills, by sampling from the negative binomial distribution.
- For each of the n spills, sample a spill size from the log normal distribution.
- Sum the n spill sizes.
- Repeat the steps until the desired sample size is reached.

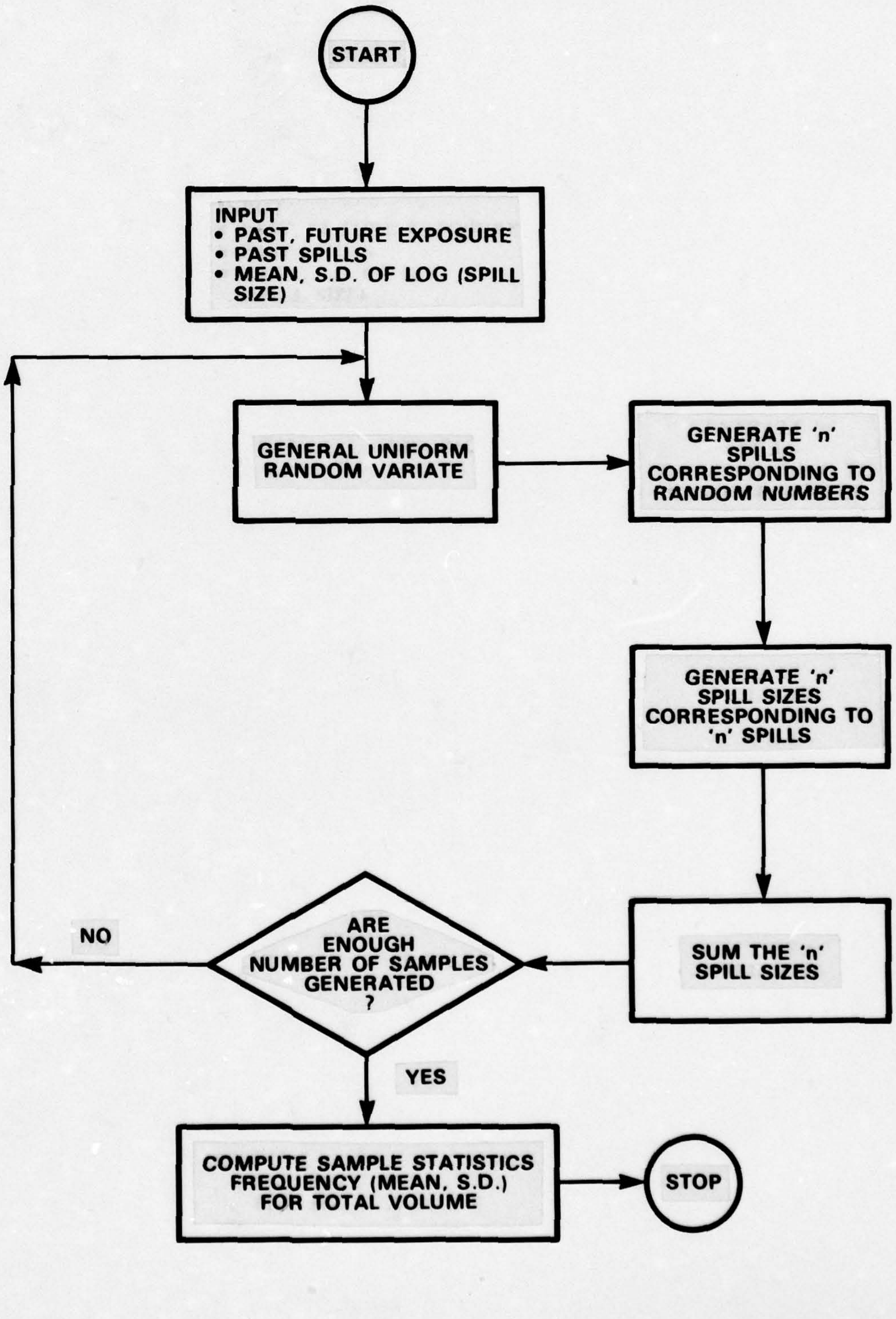
A sample size of 500 was used for the analysis.

Histograms for volume spilled over the first 5-year period and the 30-year period for LOOP and SEADOCK are shown in figures A-2 and A-13. The nonimpact casualty spill sizes during the first 5 years of operation tend to cluster at the lower end of the scale with a 95 percent probability of less than 10,000 tons spilled. Because of the higher spill rate, impact spill sizes tend to spread out more. The expected number of spills for the first 5 years is 1.1 for LOOP and 2.0 for SEADOCK.

The distribution of spill volumes tends to spread out more for the 30-year period because of the increase in the expected number of spills -- 10.9 for LOOP and

16.8 for SEADOCK. While the median value for LOOP is 38,600 long tons, there is a 10 percent probability of as much as 180,000 long tons spilled. Similarly, for SEADOCK the median is 75,400 long tons with a 10 percent probability of 283,000 long tons or more spilled.

FIGURE A-1. MONTE CARLO SIMULATION OF TOTAL VOLUME OF OIL SPILLED AT DEEPWATER PORTS



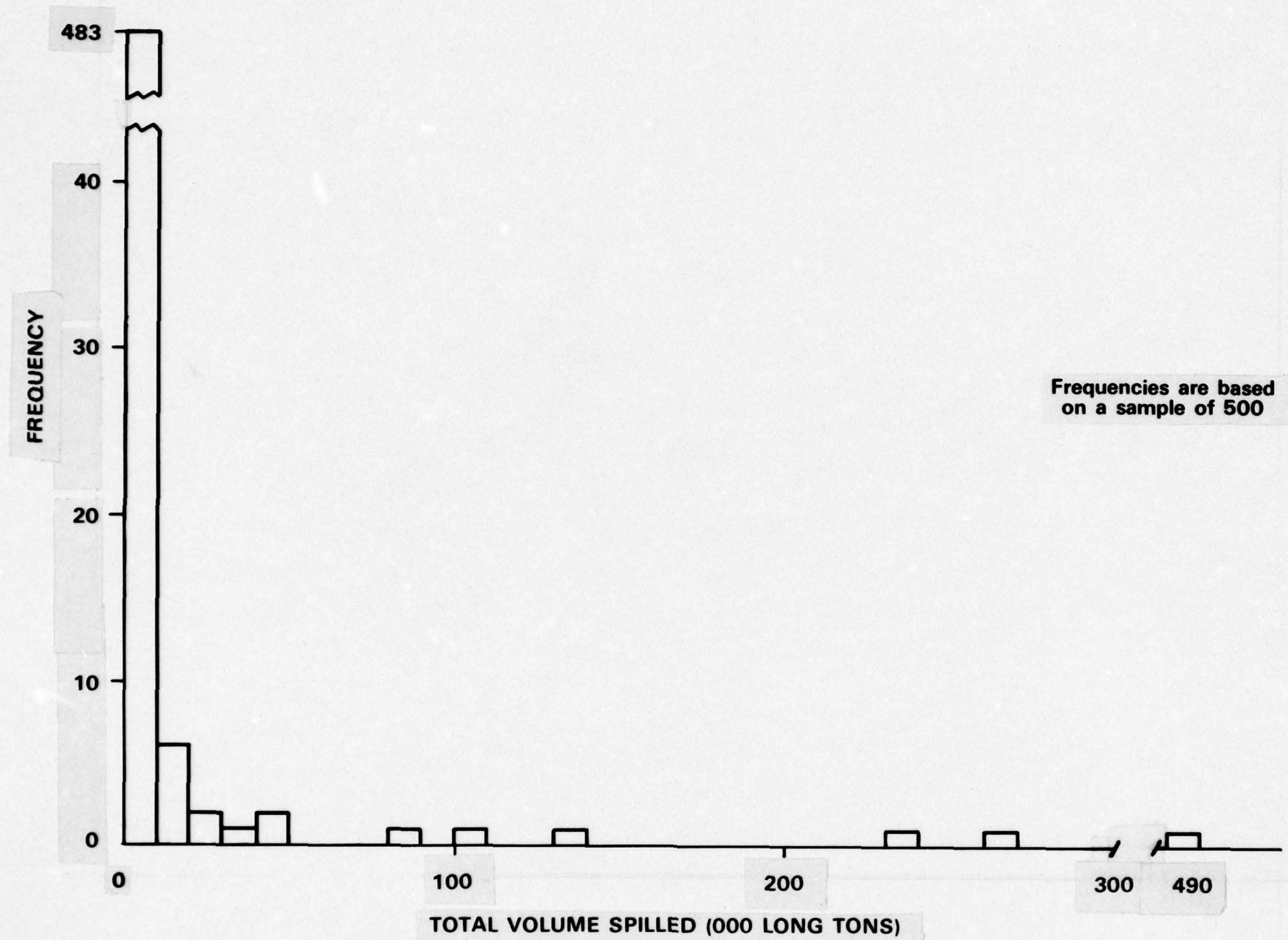


FIGURE A-2. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF NON-IMPACT CASUALTIES, LOOP 1980-1984

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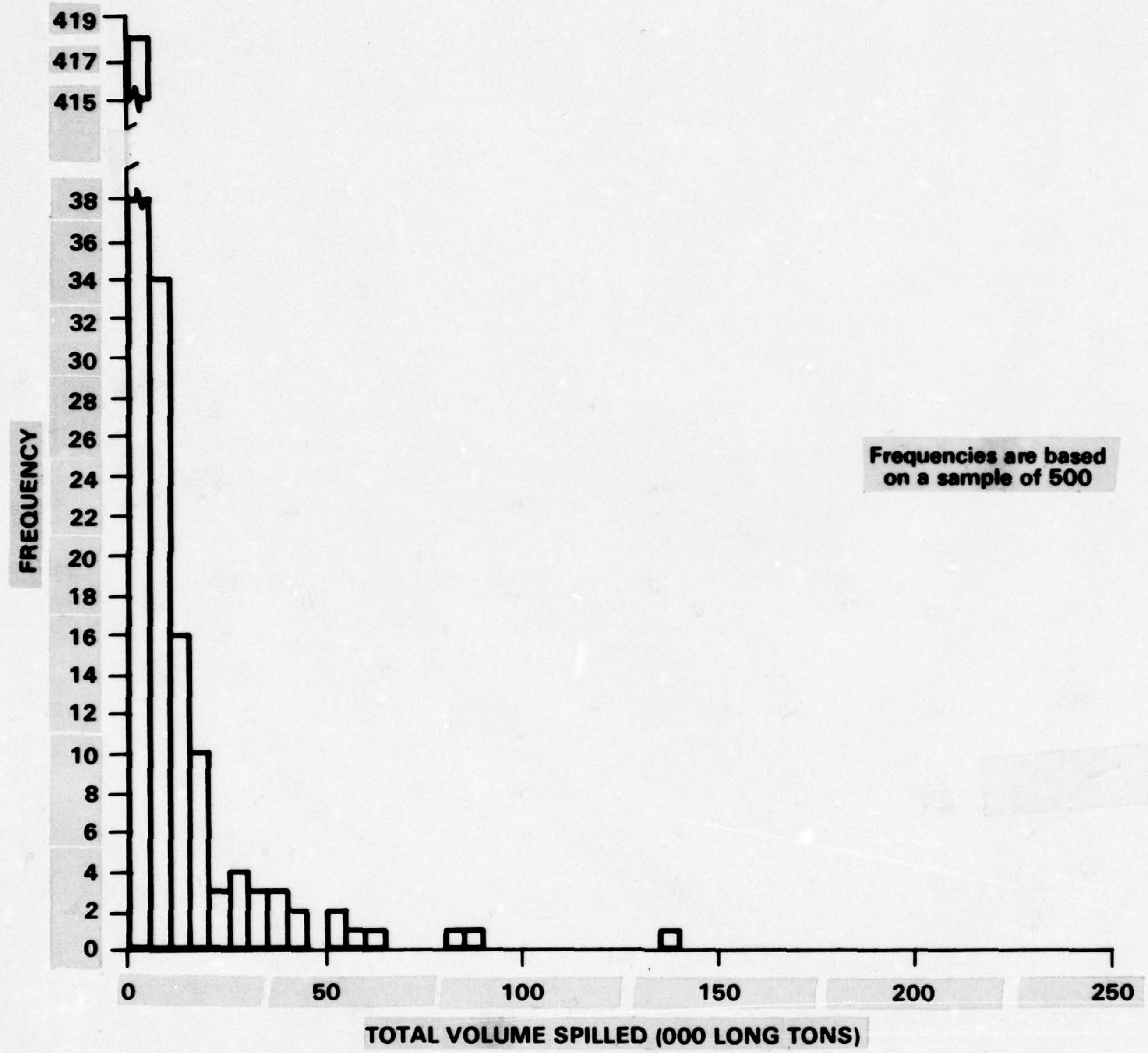

FIGURE A-3. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF IMPACT CASUALTIES, LOOP 1980-1984

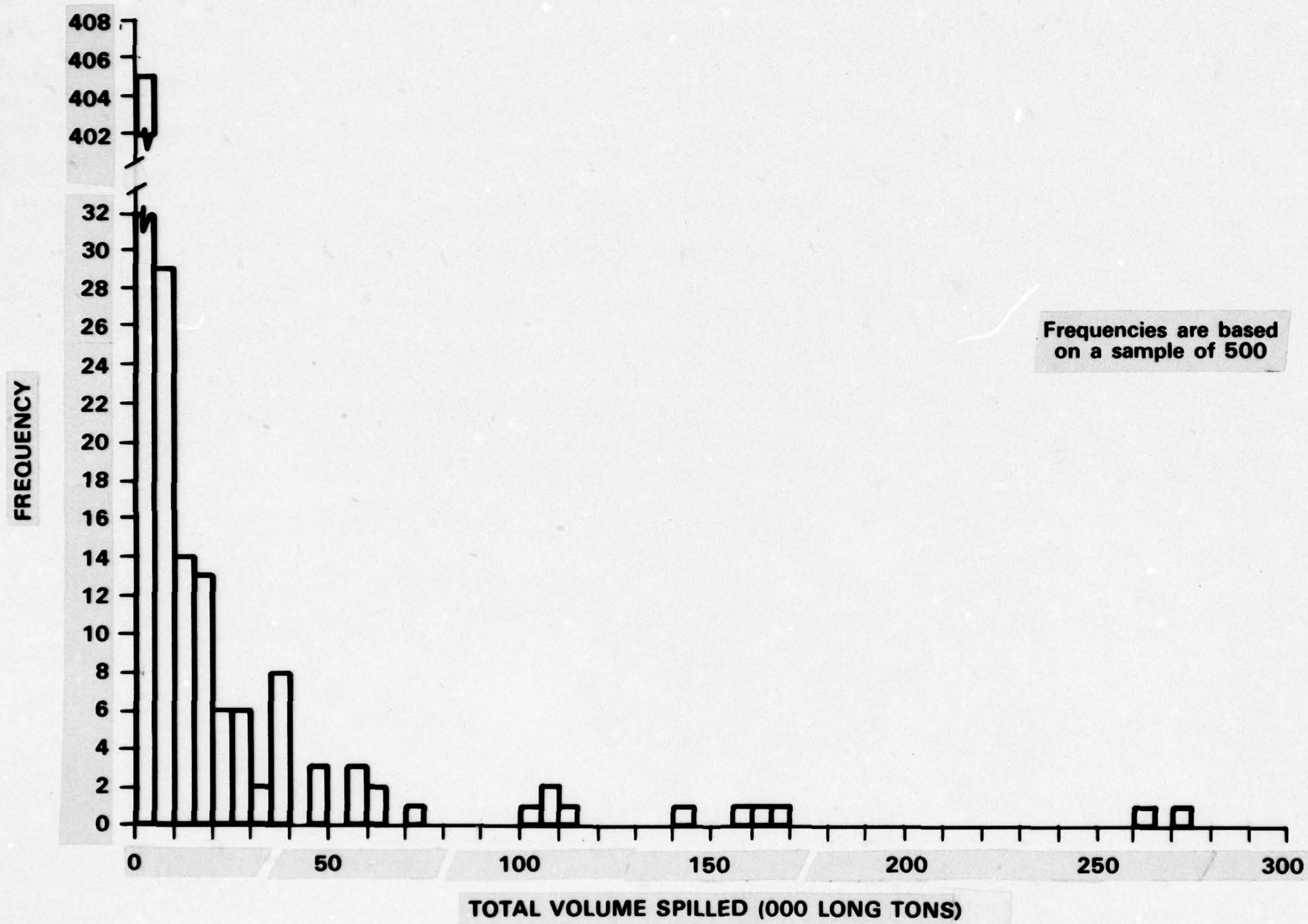

FIGURE A-4. DISTRIBUTION OF VOLUME SPILLED, LOOP 1980-1984

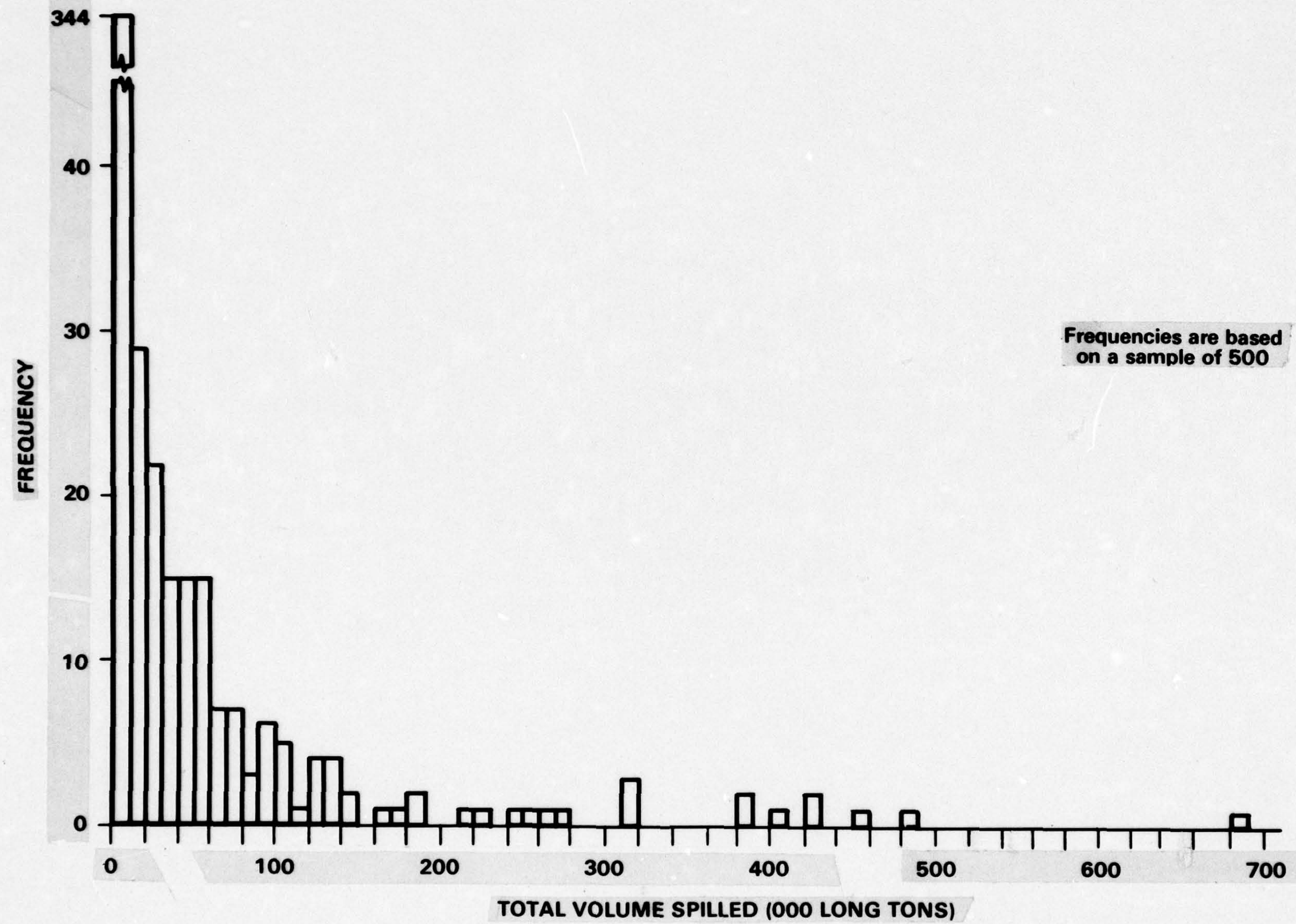

FIGURE A-5. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF NON-IMPACT CASUALTIES, LOOP 1980-2009

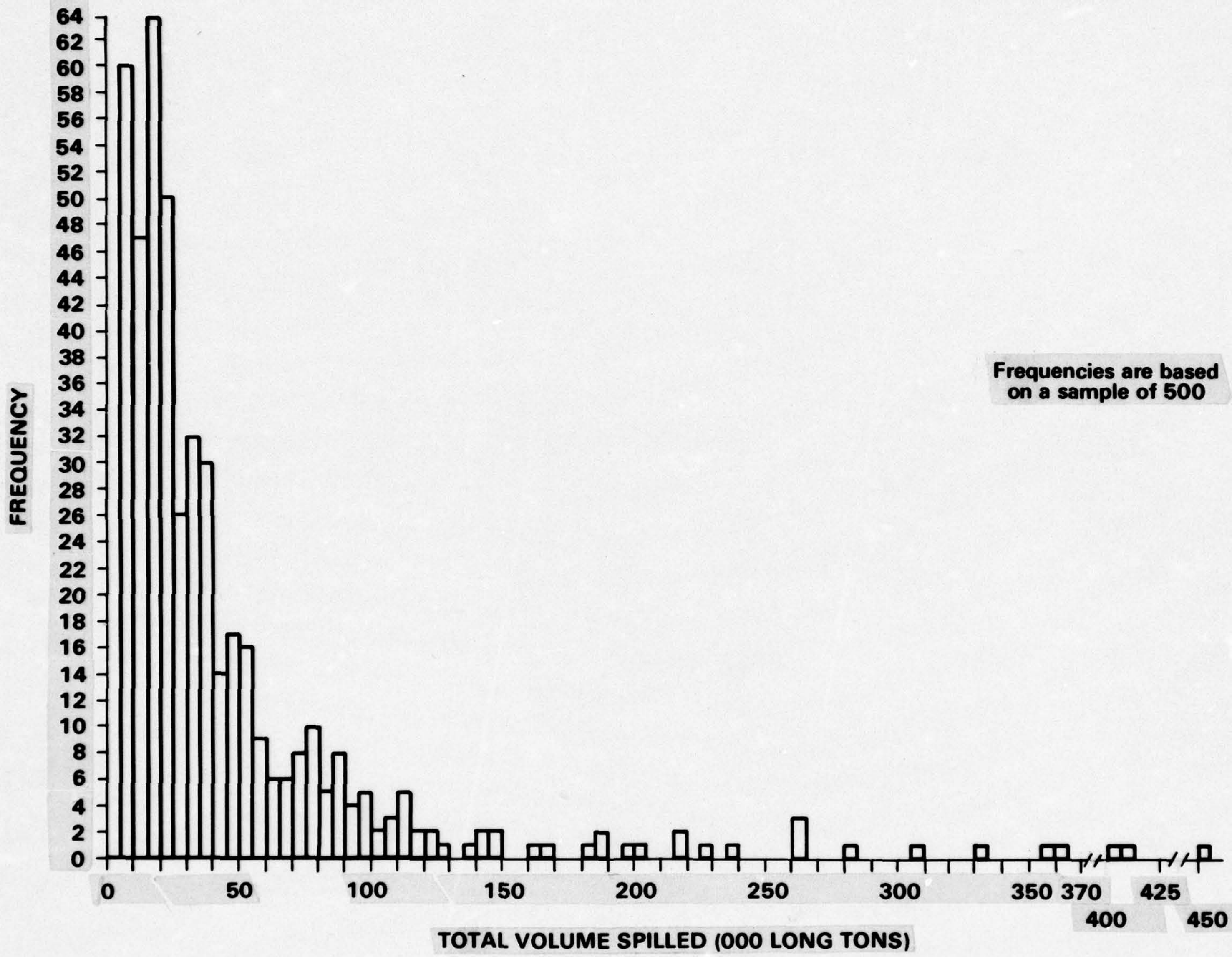

FIGURE A-6. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF IMPACT CASUALTIES, LOOP 1980-2009

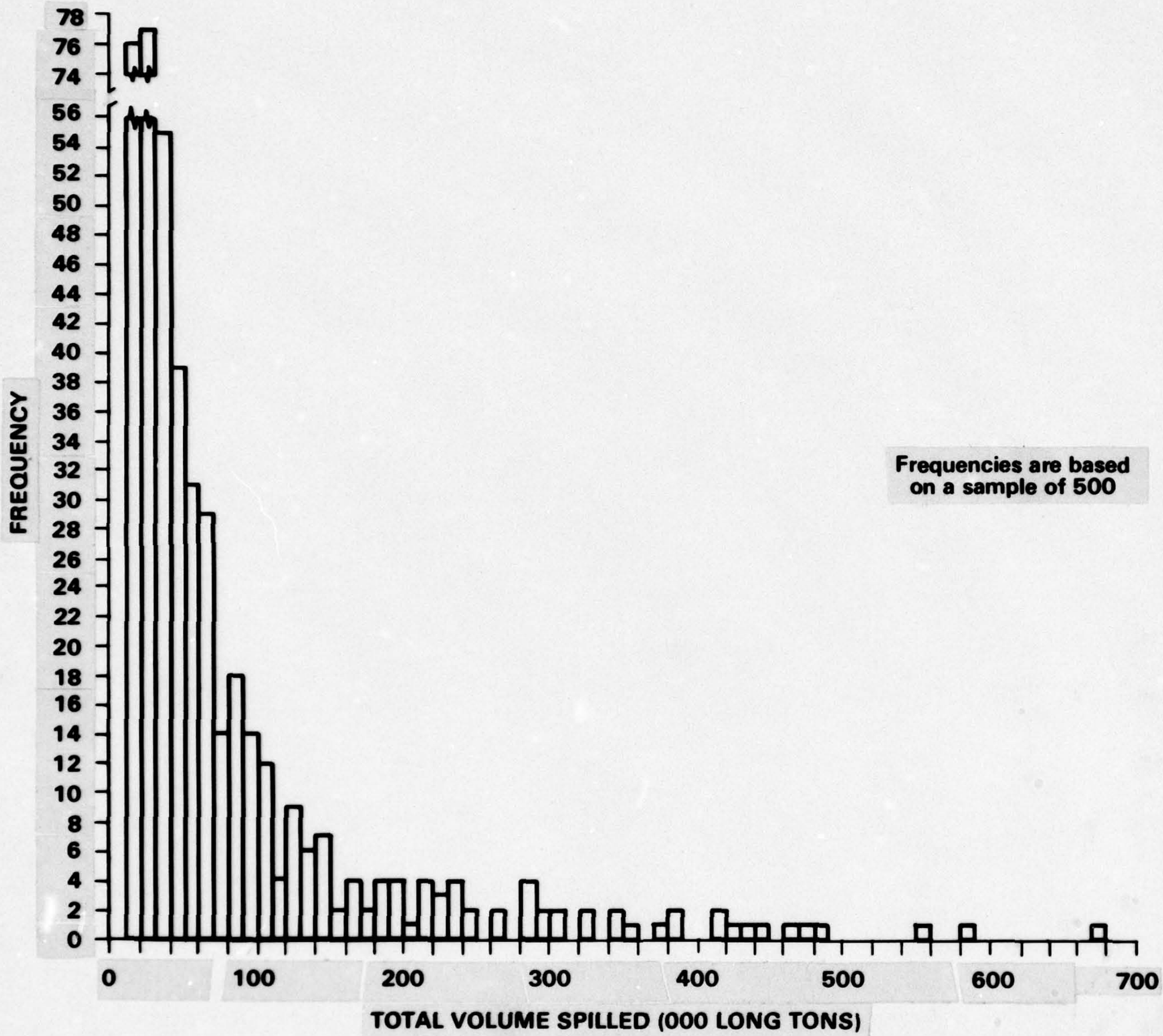

FIGURE A-7. DISTRIBUTION OF VOLUME SPILLED, LOOP 1980-2009

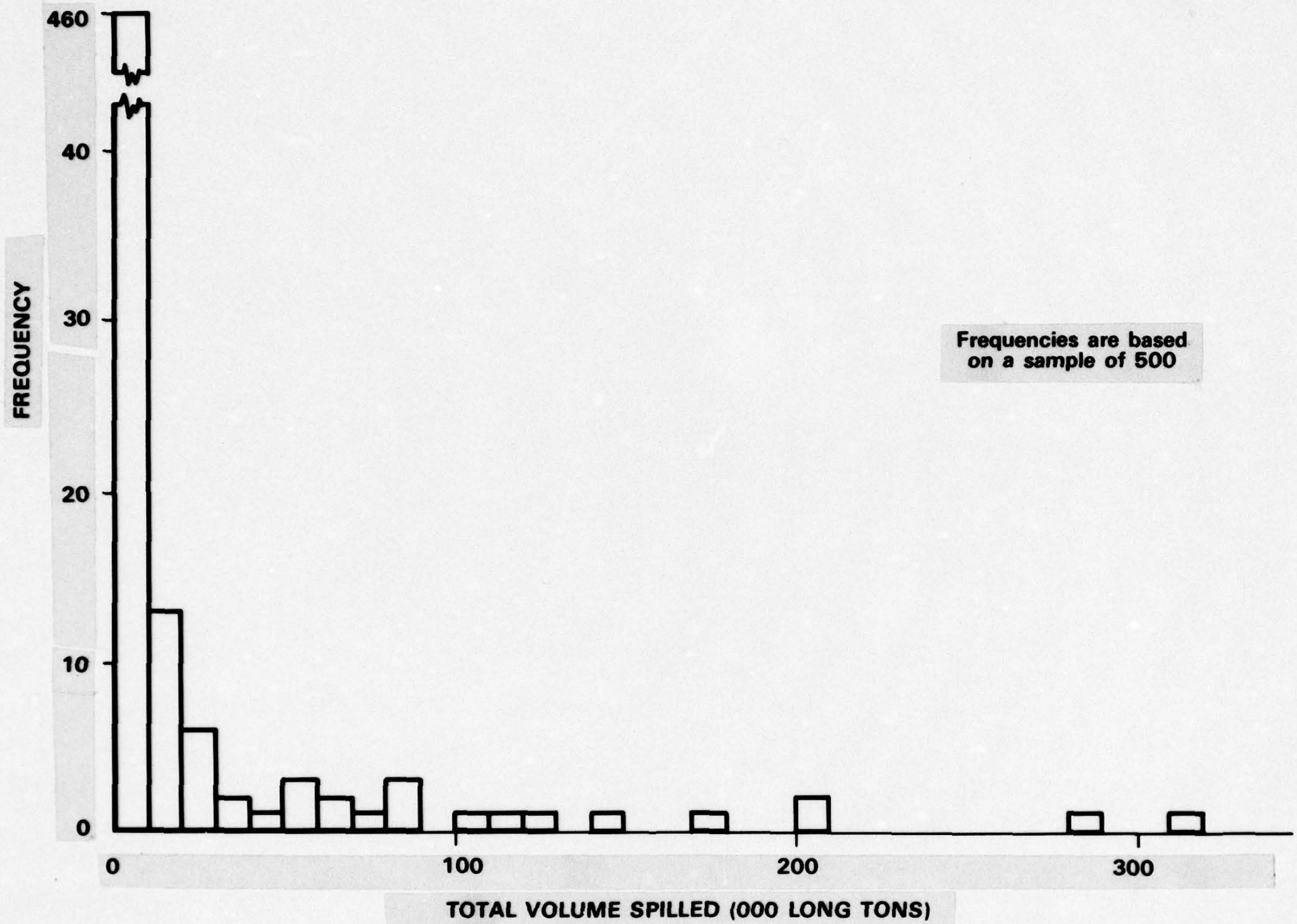

FIGURE A-8. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF NON-IMPACT CASUALTIES, SEADOCK 1980-1984

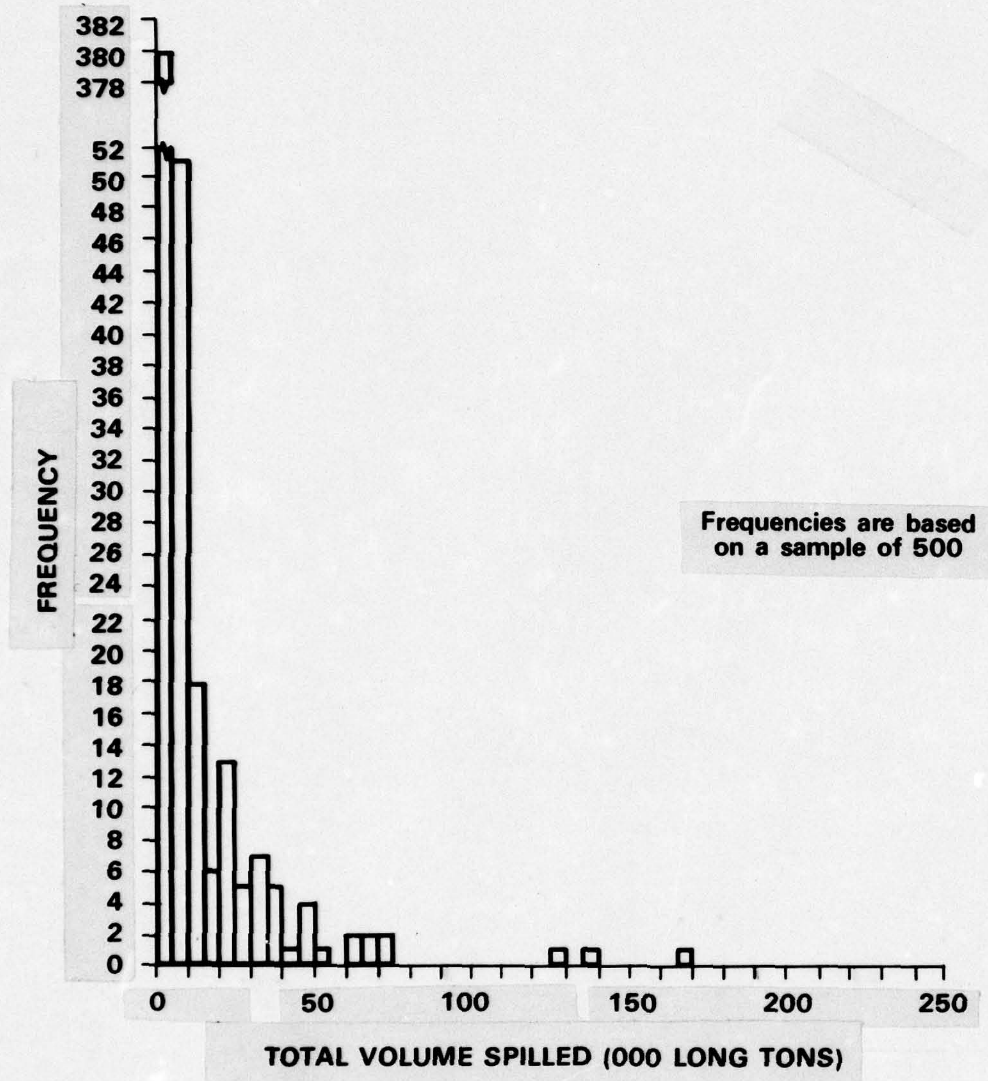

FIGURE A-9. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF IMPACT CASUALTIES, SEADOCK 1980-1984

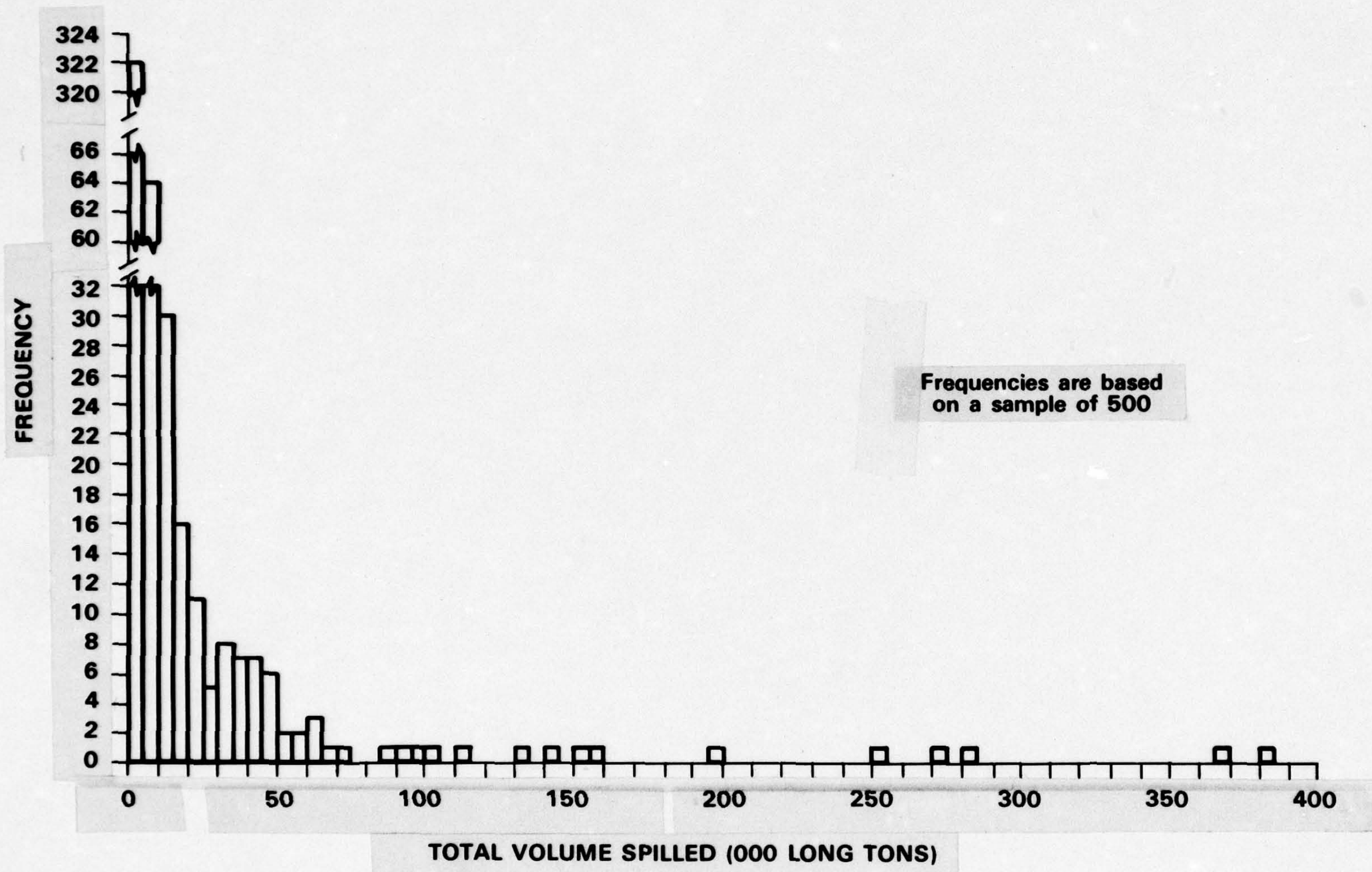

FIGURE A-10. DISTRIBUTION OF VOLUME SPILLED, SEADOCK 1980-1984

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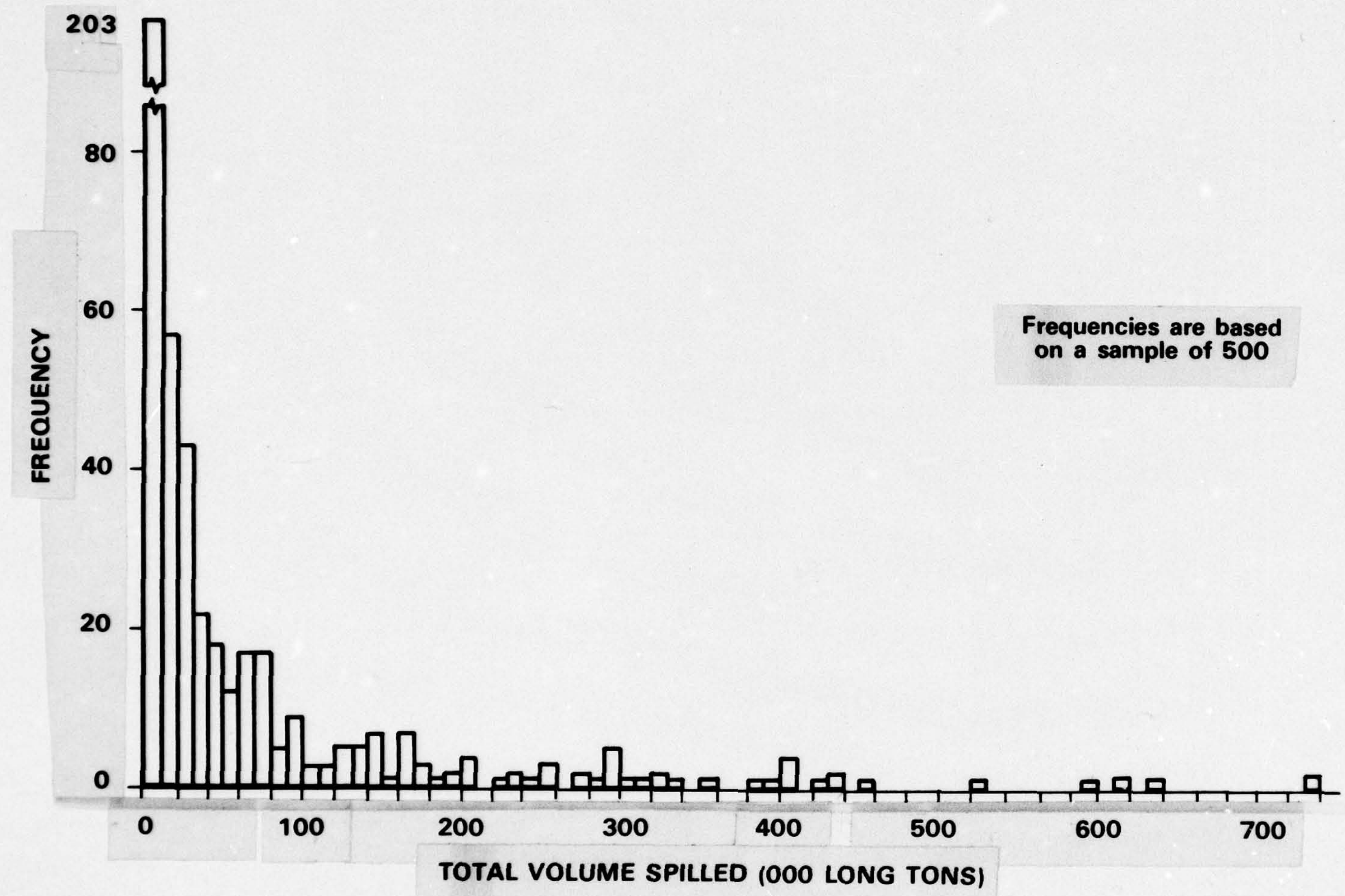

FIGURE A-11. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF NON-IMPACT CASUALTIES, SEADOCK 1980-2009

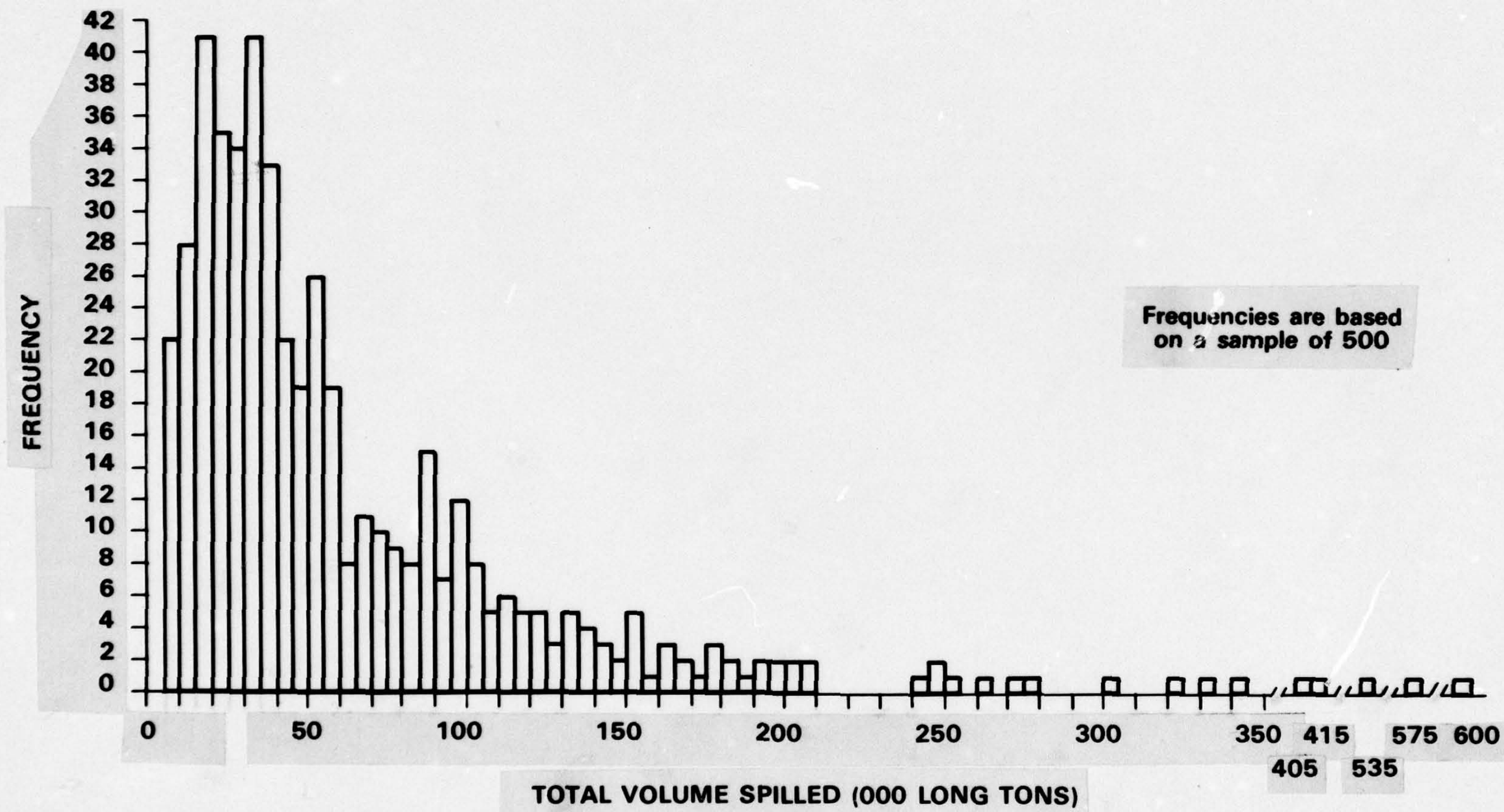

FIGURE A-12. DISTRIBUTION OF VOLUME SPILLED AS A RESULT OF IMPACT CASUALTIES, SEADOCK 1980-2009

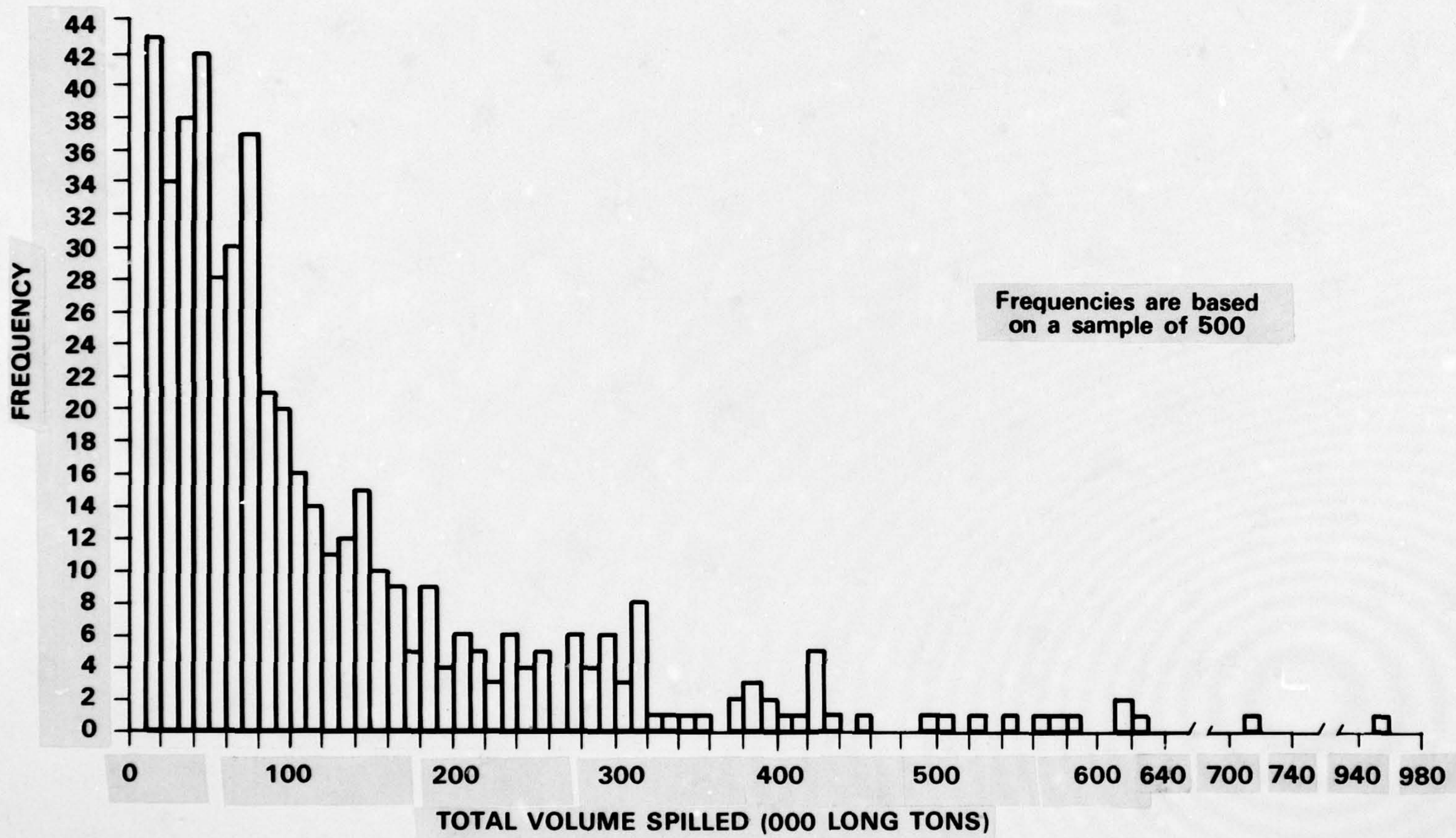

FIGURE A-13. DISTRIBUTION OF VOLUME SPILLED, SEADOCK 1980-2009

265 266 X

Appendix B

DERIVATION OF THE PROBABILITY OF AT LEAST ONE SPILL LARGER THAN A GIVEN SIZE

This appendix derives the probability of at least one spill of a size at least as large as a given size based upon the binomial distribution for the number of spills. The negative binomial distribution is given by:

$$p(n) = \binom{n + N - 1}{N - 1} \left(\frac{t}{t+T}\right)^n \left(\frac{T}{t+T}\right)^N \qquad (1)$$

where:

t = future exposure

T = past exposure

N = past number of spills

n = number of spills

Let:

x = spill size

$F(x)$ = cumulative probability of spill size, i.e., $P(x \leq X)$

The probability that all of n spills have sizes less than x is:

$$F^n(x) = (F(x))^n$$

Combining this with the probability of n spills summed over all possible values of n yields the probability of all possible spills having size less than x is $Q(x)$.

$$Q(x) = \sum_{n=o}^{\infty} p(n)F^n(x) \qquad (2)$$

Substituting the expression for $p(n)$ from equation (1) yields:

$$P(x) = 1 - \left(\frac{T}{t+T}\right)^N \sum_{n=o}^{\infty} \binom{n + N - 1}{N - 1} \left(\frac{t}{t+T}\right)^n F^n(x) \qquad (3)$$

The probability of at least one spill greater than size x is:

$$P(x) = 1 - Q(x)$$

Substituting:

$$p = \frac{T}{t+T}$$

$$q = \frac{t}{t+T}$$

$$a = N - 1$$

allows the following simplification:

$$P(x) = 1 - p^{a+1} \sum_{n=o}^{\infty} \binom{n+a}{a} (q\,F(x))^n \tag{4}$$

The *infinite* series is simply:

$$\left[1 - qF(x)\right]^{-(a+1)}$$

Thus,

$$P(x) = 1 - p^{a+1}\left[1 - qF(x)\right]^{-(a+1)} \tag{5}$$

Resubstituting for a, p, and q results in:

$$P(x) = 1 - \left(\frac{T}{t+T}\right)^N \left[1 - \left(\frac{t}{t+T}\right) F(x)\right]^{-N} \tag{6}$$

This equation can be simplified to:

$$P(x) = 1 - \left\{1 + \frac{t}{T}\left(1 - F(x)\right)\right\}^{-N} \tag{7}$$

Appendix C
LOWER BOUNDS ON THE CUMULATIVE SPILL SIZE DISTRIBUTION

The evaluation of the probability of relatively rare events often presents problems because of the paucity of data. This is the case for large scale oil spills. Probability distributions that are fitted to data generally result in very poor fits in the extreme tails, as in the case of the spill size distributions. For this reason, probability bounds were developed for estimating probabilities in these regions rather than relying on the fitted distributions. Two bounds were estimated, based on the Chebycheff and the Gauss inequalities.

Chebycheff's inequality is given by:

$$\Pr.\ \{|x-a| \geq ts\} \leq \frac{1}{t^2} \tag{1}$$

Where t is a constant, a = means and s = standard deviation of a distribution on x, the random variable. Equation (1) can be rewritten as:

$$\Pr.\ \{|x-a| \leq ts\} \geq 1-\frac{1}{t^2} \tag{2}$$

In the present context, x, the spill size, is the random variable of interest. We know that the mean a (from the historical data) is far smaller than the spill size x being considered. Thus, equation (2) becomes:

$$\Pr.\ \{x \leq ts\} \geq 1-\frac{1}{t^2} \quad \text{for } x >> a \tag{3}$$

Any spill size, x, can be represented as a multiple, t, of the standard deviation, s. Thus, we have:

$$\Pr.\ \{x \leq X\} = F(x) \geq 1-s^2/x^2 \tag{4}$$

where:

x = ts

F(x) = cumulative distribution in x.

Thus, equation (4) determines a lower bound on F(x).

The Chebycheff inequality holds for any distribution for which a mean and standard deviation exist. If the distribution is unimodal and continuous, a much tighter upper bound can be computed. This was given by Gauss[1] and is as follows:

$$\text{Probability } (|x-a| \geq ts) \leq \frac{4}{9} \frac{1+\lambda^2}{(t - |\lambda|)^2} \tag{5}$$

where λ the Pearsonian measure of skewness and is defined as:

$$\lambda = \frac{\text{mean - mode}}{\text{standard deviation}}$$

As before, equation (5) can be written as:

$$P\,(x \leq X) = F(x) \geq 1 - \frac{4}{9} \frac{1 + \lambda^2}{(x/s - |\lambda|)^2} \tag{6}$$

This results in a more stringent bound on F(x) than does the Chebycheff inequality.

The following data for spill sizes were extracted from the Tanker Casualty File:

	Impact	Non-Impact
Mean (Long Tons)	4,023	11,635
Mode (Long Tons)	10	5
Standard Deviation (Long Tons)	14,304	13,092
λ (Skewness)	.281	0.888

Cramer[2] notes that for moderate values of λ (around .25), Gauss' bound is much more precise than Chebycheff's bound. Table C-1 presents a comparison of these bounds on 1-F(x) computed for impact and non-impact spills for spills of 220,000 and 109,524 long tons. As can be seen, Gauss' bound is about half that of Chebycheff's for impact spills. However, for non-impact spills there does not seem to be a significant

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1. H. Cramer, Mathematical Methods of Statistics (Princeton University Press, 1946), p. 183.
2. Ibid.

difference. This seems to confirm Cramer's note. Since the Gauss bound is significantly smaller for impact casualties and since it conditions appear to be met, these values were used in the computation of the probability of a spill of size greater than a given size, P(x).

The bounds of table C-1 represent mathematical upper bounds on 1-F(x), the probability of a spill at least as large as x, based upon the mean, mode, and standard deviation of F(x). For the application to the analysis in this report, these parameter values were obtained from the historical spill size data. If future spill sizes exhibit different characteristics than those in the past (say, larger means or greater variation), the bounds will no longer apply. If the future spill sizes follow the statistical pattern of those used in this analysis, the upper bound implies that the probability of spills exceeding the specified value will be no larger than the values shown in the table. In other words, over a sufficiently large number of spills the proportion exceeding those sizes will be less than the values derived from the bounds.

TABLE C-1. BOUNDS ON THE CUMULATIVE SPILL SIZE DISTRIBUTION VALUES

Spill Size (Long Tons)	Casualty Type	Bounds on 1 -F(x) Chebycheff	Gauss
220,000	Impact	.0042	.0021
	Non-Impact	.0035	.0031
109,524	Impact	.0171	.0088
	Non-Impact	.0143	.0142

APPENDIX D
FAULT TREE ANALYSIS

The figures on the following pages depict the fault trees. Figure D-1 identifies the symbols and abbreviations used. The top-level fault tree is shown in figure D-2. Figures D-3 through D-18 cover the second level trees, and the itemized lists associated with the figures provide the third level. As can be seen from these figures, following any path from the bottom-most to the top-most level (or vice versa) yields an accident scenario.

FIGURE D-1. FAULT TREE SYMBOLS AND ABBREVIATIONS

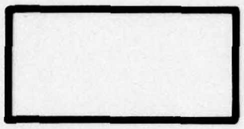
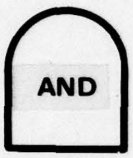
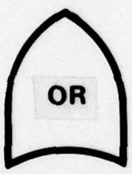
SYMBOL/ABBREVIATION	DEFINITION
	AN EVENT OR CONDITION, AS DESCRIBED WITHIN THE BLOCK
	"AND" GATE; OUTPUT OCCURS IF ALL INPUTS OCCUR
	"OR" GATE; OUTPUT OCCURS IF ANY ONE (OR MORE) INPUT OCCURS
	CONTINUATION TO ANOTHER TREE, OR ANOTHER PORTION OF SAME TREE. ARROW INDICATES DIRECTION OF CONTINUATION; LETTER IN TRIANGLE PROVIDES IDENTIFICATION
	SHORTHAND "OR" GATE INPUT FROM LOWEST LEVEL CONTRIBUTING FACTORS; SYMBOL IN CIRCLE IDENTIFIES THESE CONTRIBUTING FACTORS
LTA	LESS THAN ADEQUATE
LOP	LINE OF POSITION
DWP	DEEPWATER PORT
DR	DEAD RECKONING
ETA	ESTIMATED TIME OF ARRIVAL
PPI	PLAN POSITION INDICATOR

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE

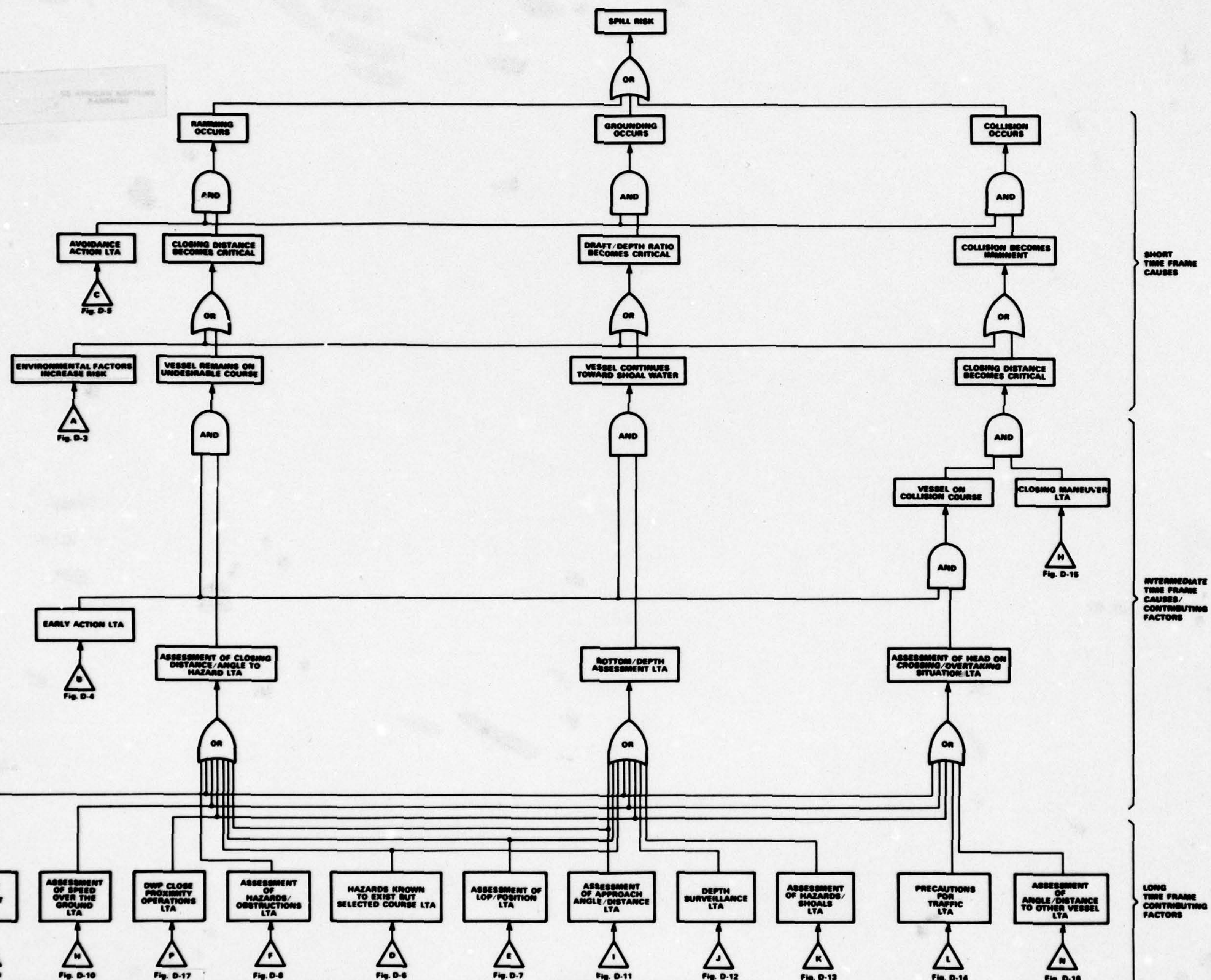


FIGURE D-3. ENVIRONMENTAL FACTORS INCREASE RISK

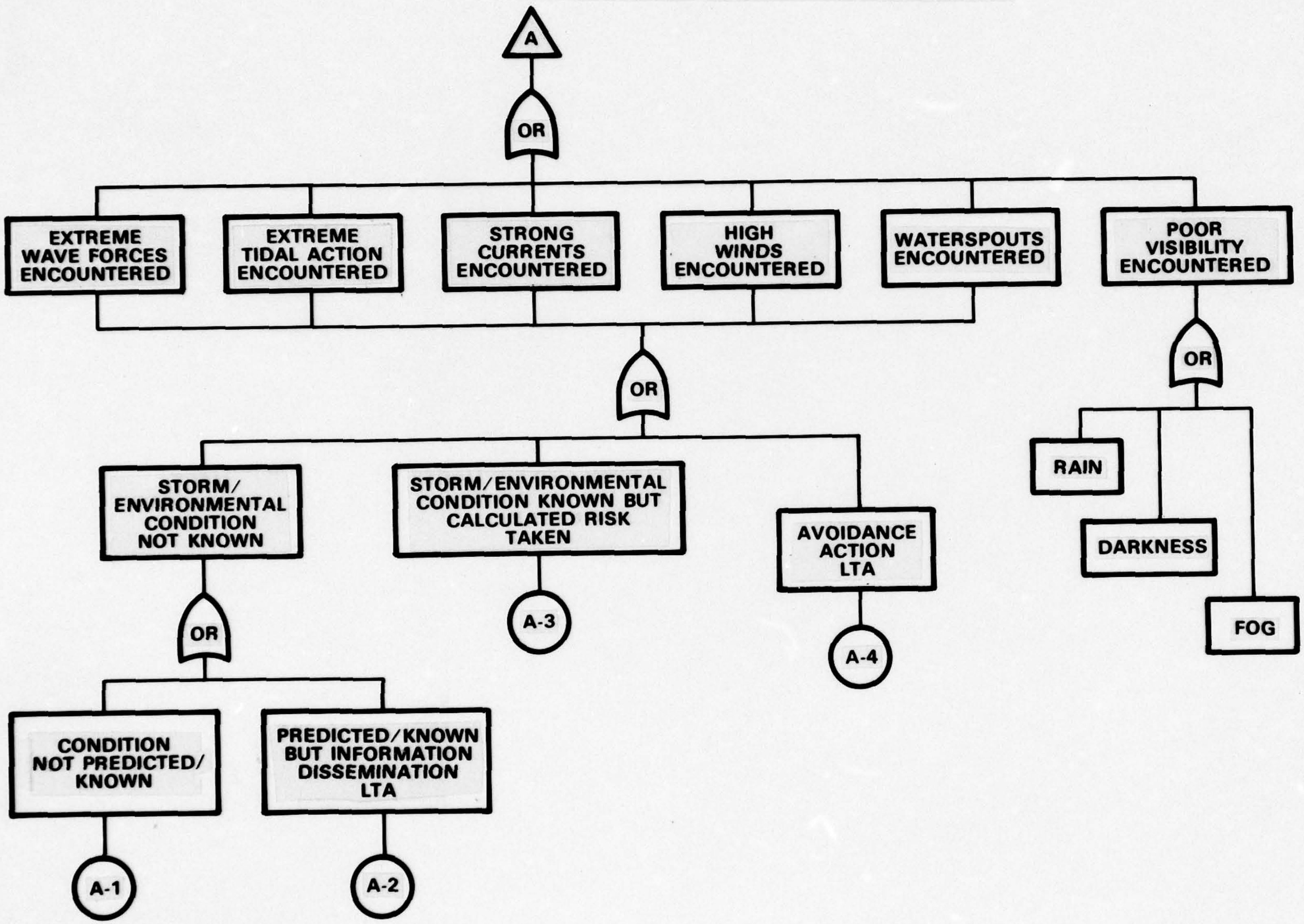


Figure D-3

Environmental Factors Increase Risk

Common to: Collision, Ramming, Grounding

A-1 Condition Not Predicted/Known

1. Beyond forecasting capabilities to predict
2. Condition developed too rapidly for early detection
3. Local condition not monitored by meteorological services
4. Indications of conditions misinterpreted by meteorological services
5. "Rogue wave," i.e., "rogue sea."
6. Swell created by distant storm
7. Wind roses on charts inaccurate
8. Wind roses on charts not consulted
9. Current information on charts not accurate
10. Current information on charts not consulted
11. Possible environmental conditions inaccurately described in Coast Pilot/Sailing Directions
12. Coast Pilot/Sailing Directions not consulted regarding possible environmental conditions
13. Shipboard meteorological equipment (facsimile equipment, barometer) inoperable
14. Shipboard meteorological equipment not monitored
15. Forecasts (NOAA/CG/WWV) not monitored
16. Other

A-2 Predicted/Known But Information Dissemination LTA

1. Excessive time delay between identification of condition and broadcast notice by meteorological services
2. Content of broadcast information not clear
3. Descriptions of potential conditions in Coast Pilot/Sailing Directions not clear
4. Wind roses on charts subject to misinterpretation
5. Current information on charts subject to misinterpretation
6. Radio transmission bands (facsimile, voice, teletype, etc.) subject to interference
7. Poor resolution of radio transmissions

8. Information not relayed by shipping company/shipboard personnel
9. Broadcast schedules LTA
10. Broadcast schedules not adhered to
11. Information received on board but not relayed to conning officer
12. Other

A-3 Storm/Environmental Condition Known But Calculated Risk Taken

1. Master underestimates severity of condition
2. Master feels conditions will not jeopardize passage/vessel
3. Shipping company imposes pressure regarding maintaining schedule
4. Master feels condition will dissipate before encountered
5. Other situation (e.g., need for repair, medical attention, etc) given higher priority
6. Calculated risk based on poor or superficial evaluation of condition
7. Other

A-4 Avoidance Action LTA

1. Plans to avoid condition fail due to change in course of adverse weather
2. Action taken too late to avoid condition
3. Vessel's course change not adequate to avoid condition
4. No action taken; negligence
5. Other

FIGURE D-4. EARLY ACTION LTA

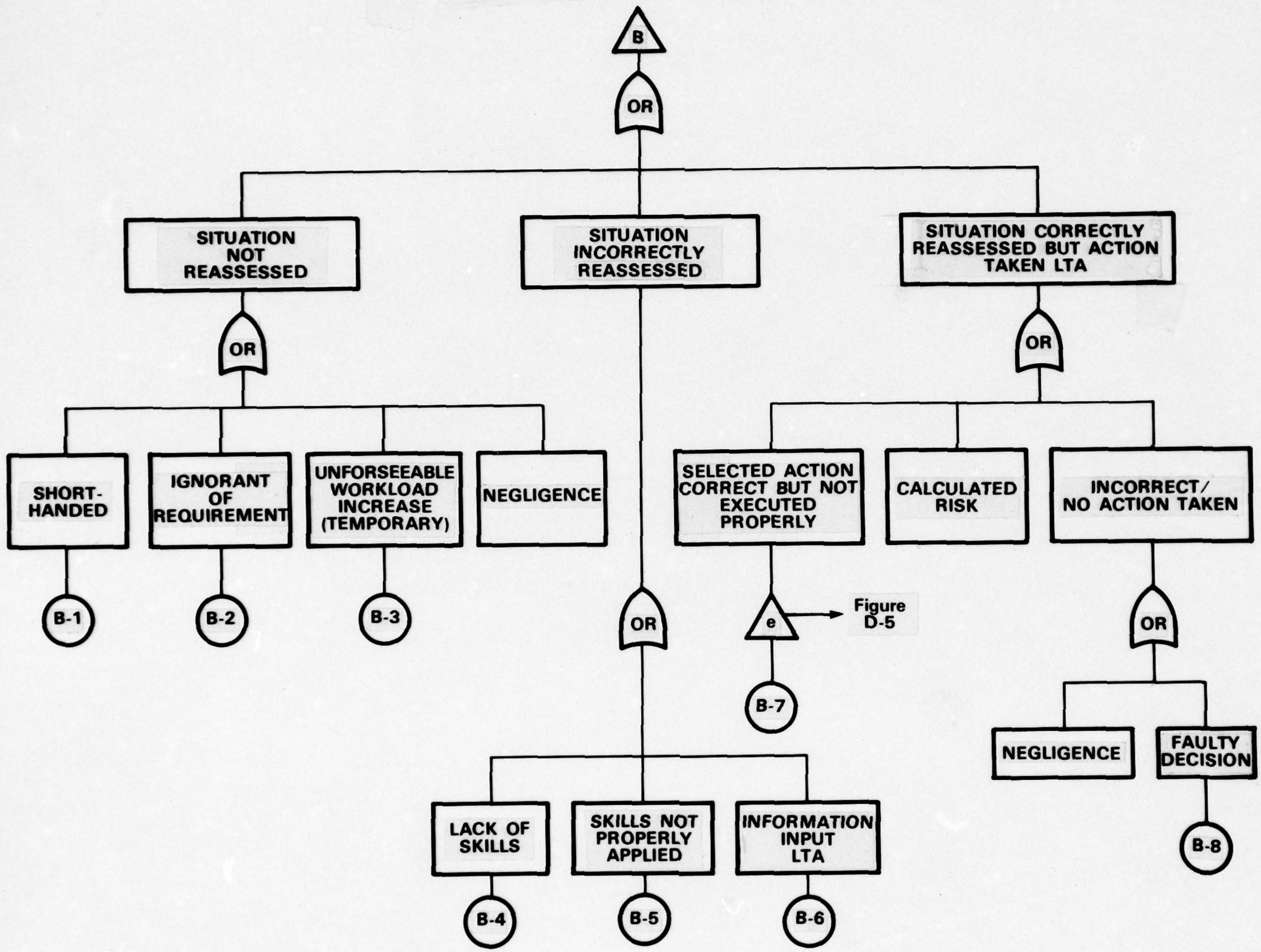


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Figure D-4

Early Action LTA

Common to: Collision, Ramming, Grounding

B-1 <u>Situation Not Reassessed; Short Handed</u>

1. Bridge officers too busy with other duties (logging engine room orders, etc.)
2. Non-optimal bridge layout imposes additional workload
3. Non-optimal equipment (e.g., radar, radiotelephone, etc) operating requirements impose additional workload
4. Crew member engaged in routine duty at the expense of critical duty
5. Master/shipping company earlier made/imposed the decision to sail short-handed
6. Crew member taken sick
7. Crew member under the influence of alcohol/drugs
8. Other

B-2 <u>Situation Not Reassessed; Ignorant of Requirements</u>

1. Potential criticality of situation not appreciated
2. Reassessment erroneously assumed to be someone else's responsibility
3. Crewman not instructed to watch for certain condition/feature/navaid
4. Bridge officer doesn't appreciate requirement to check for earlier LTA condition
5. Inadequate communication at change of watch leads to unawareness of potential situation
6. Misinterpretation of navaids leads to false reassurance that all is well
7. Other

B-3 <u>Unforeseeable Workload Increase (Temporary)</u>

1. Master distracted due to crew problems
2. Master distracted due to mechanical problems
3. Mistake by bridge officer requires time consuming corrective action (e.g., time spent correcting a plotting mistake)
4. Master distracted by preparations for adverse weather conditions

5. Master distracted by ship's business

6. Other

B-4 Situation Incorrectly Reassessed; Lack of Skills

1. Radar interpretation incorrect
2. Fathometer/lead line reading incorrect
3. Chart misinterpreted
4. Light list/coast pilot/sailing directions misinterpreted
5. Range lights misinterpreted
6. Electronic fix incorrect
7. Visual fix incorrect
8. Fix incorrectly plotted
9. Navaids incorrectly identified
10. Sound signals incorrectly identified
11. Intentions of other vessel misinterpreted
12. Other

B-5 Skills Not Properly Applied

1. Given navaid mistaken for a different one
2. Radar interpretation incorrect
3. Lights incorrectly interpreted
4. Wrong scale chart used
5. Sound signals misinterpreted
6. Out-of-date Coast Pilot/Light List/Local Notice to Mariners consulted
7. Wrong information conveyed at change of watch
8. Fathometer/lead line reading incorrect
9. Other

B-6 Information Input LTA

1. Not all available navaids considered
2. Failure to augment charted position with visual/electronic fixes
3. Ranges not taken
4. Ship's track not projected far enough
5. Coast Pilot/Light List/Local Notice to Mariners not consulted

6. Radar setting insufficient for required range (e.g., radar set on short scale)
7. Radar not operative
8. Portion of radar scan obstructed (e.g., by vessel's mast)
9. Radar degraded (e.g., reduced target intensity, incorrect scan, etc.)
10. Sound signals not heard
11. Sound signals not operative
12. Sound signals degraded (e.g., reduced level, altered characteristics, etc.)
13. Electronic navaids not operative
14. Electronic navaids degraded (e.g., reduced coverage, altered characteristics, etc.)
15. Insufficient coverage of electronic navaids
16. External interference (e.g., atmospherics, naval electronic warfare exercises, ham rigs, etc.) degrades electronic navaid reception
17. Radio beacon inoperative
18. Radio beacon degraded (e.g., reduced range, altered characteristics, etc.)
19. Light(s) on navaids not operative
20. Light(s) on navaids degraded (e.g., reduced intensity, not rotating, etc.)
21. Navigation light(s) burned out - own vessel
22. Navigation light(s) burned out - other vessel
23. Navigation light(s) improper - own vessel (e.g., reduced sector coverage, broken lens, etc.)
24. Navigation light(s) improper - other vessel (e.g., reduced sector coverage, broken lens, etc.)
25. Ship's maneuvering characteristics not considered -own vessel
26. Ship's maneuvering characteristics not considered - other vessel
27. Posted maneuvering characteristics not applicable for given situation (e.g., data derived for other loading/water conditions)
28. Ship's maneuvering characteristics not posted
29. Intentions of other vessel not considered
30. Other

B-7 <u>Selected Action Correct But Not Executed Properly</u>

1. Inadequate communication between watch-standers, verbal.
2. Communications devices (e.g., walkie-talkies) not provided.
3. Communications devices (e.g., walkie-talkies) not operative.

4. Communications devices (e.g., walkie-talkies) degraded (e.g., volume control broken).
5. Engine order telegraph malfunctioning.
6. Engine order telegraph not adequately monitored.
7. Engine room orders not adequately executed (e.g., slow response, wrong response, etc.).
8. Gear failure (e.g., anchor winch).
9. Short handed due to temporary overload (e.g., watch-stander(s) diverted to other task).
10. Short-handed due to "steady state" workload (e.g., crew size not adquate).
11. Competence compromised by drugs/alcohol.
12. Competence compromised by illness/health problem (e.g., deafness).
13. Panic.
14. Incompetence.
15. Skills deficiency.
16. Fatigue.
17. Personal animosity.
18. Insubordination.
19. Newly assigned crew member(s) not adequately familiar with vessel.
20. Other.

B-8 Incorrect/No Action Taken; Faulty Decision

1. Procrastination.
2. Indecisiveness.
3. Decision based on incorrect information.
4. Judgment error.
5. Lack of experience.
6. Maneuvering capabilities overestimated.
7. Timeliness requirements incorrectly estimated.
8. Potential criticality of situation not appreciated.
9. Decision incorrectly expected of someone else.
10. Other.

FIGURE D-5. AVOIDANCE ACTION LTA

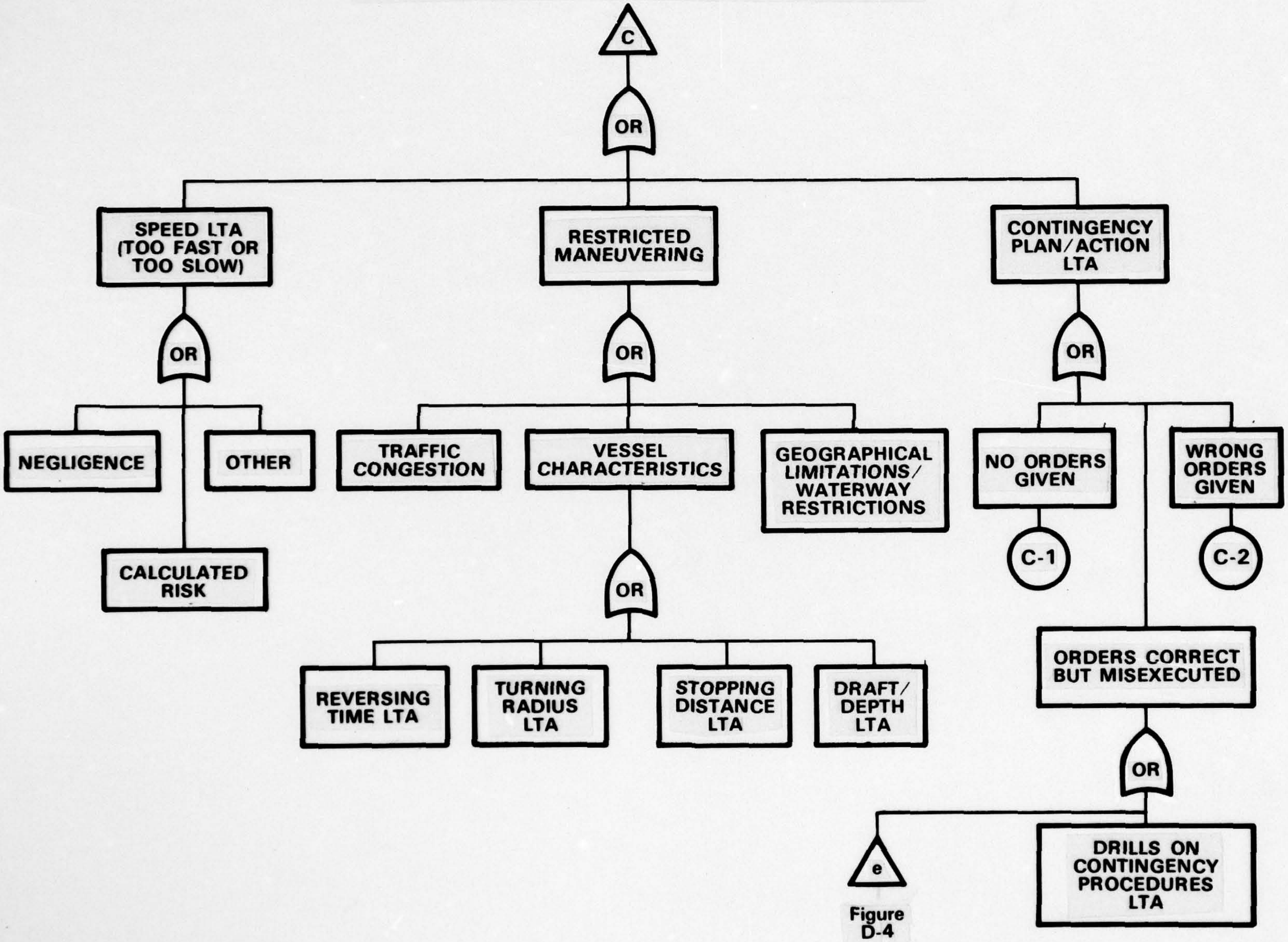

Figure D-5

Avoidance Action LTA

C-1 No Orders Given

1. Procrastination
2. Indecisiveness
3. Panic
4. Judgment error
5. Timeliness requirements incorrectly estimated
6. Criticality of situation not appreciated
7. Orders incorrectly expected of someone else
8. Fatigue
9. Under the influence of drugs/alcohol
10. Illness
11. Contingency plan not previously considered
12. Other

C-2 Wrong Orders Given:

1. Panic
2. Judgment error
3. Inadequate prior contingency planning/drills
4. Criticality of situation not appreciated
5. Skills deficiency
6. Fatigue
7. Illness
8. Drugs/alcohol
9. Incompetence
10. Other

FIGURE D-6. HAZARD KNOWN TO EXIST BUT SELECTED COURSE LTA

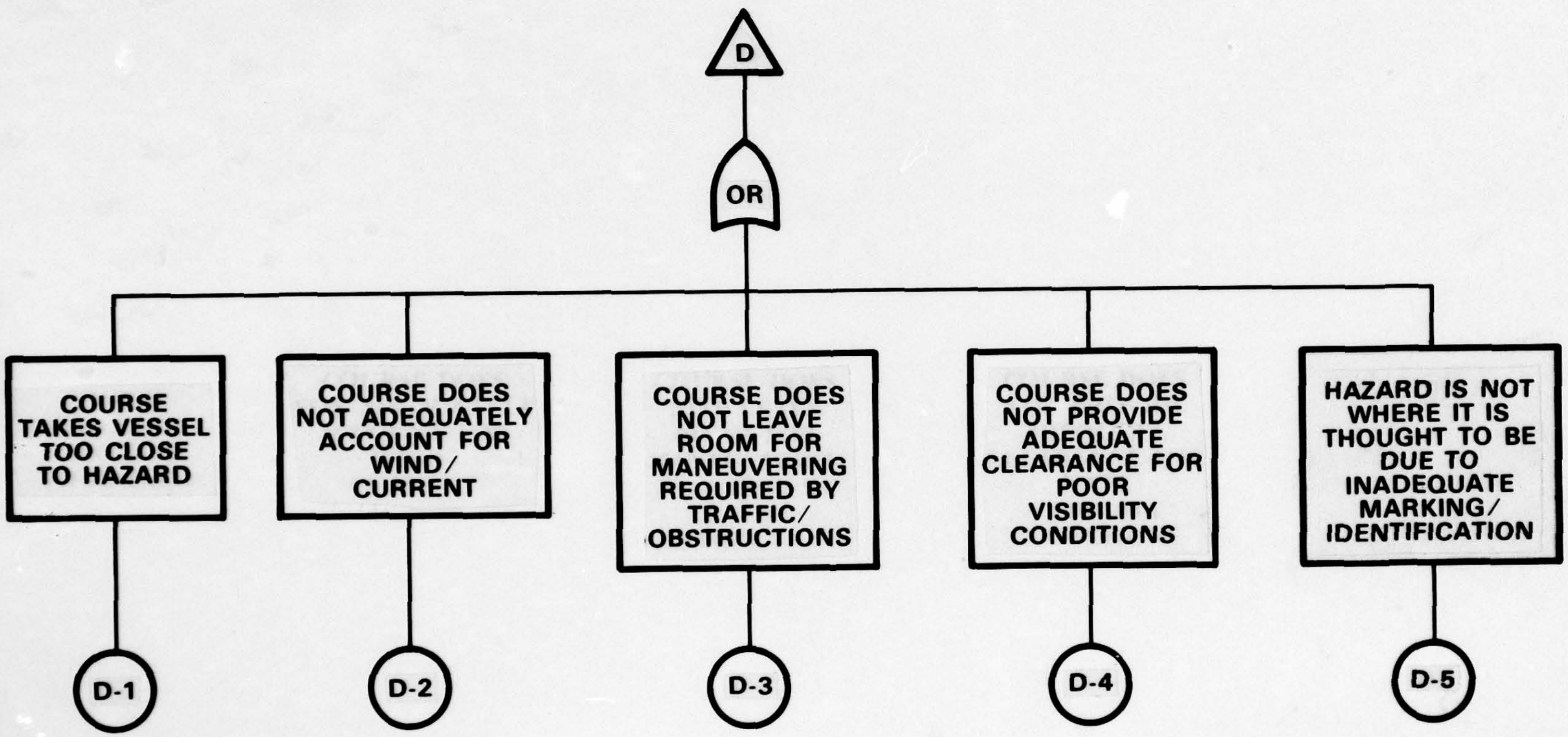

Figure D-6

Hazard Known to Exist But Selected Course LTA

D-1 Course Takes Vessel Too Close to Hazard:

1. Calculated risk
2. Negligence
3. Incompetence
4. Vessel's manuevering capabilities overestimated
5. Lack of experience
6. Charting procedures inadequate-heavy workload
7. Coast Pilot/Sailing Directions misinterpreted
8. Coast Pilot/Sailing Directions not consulted
9. Wrong scale chart used
10. Course selected on the basis of saving time (e.g., as a means of meeting schedule, to reduce cost through reduction in running time, etc.)
11. Other

D-2 Course Does Not Adequately Account for Wind/Current

1. Current information on charts not consulted
2. Current information on charts inaccurate
3. Coast Pilot/Sailing directions not consulted
4. Coast Pilot/Sailing directions not accurate
5. Freak current
6. Wind not considered
7. Wind incorrectly assessed
8. Current incorrectly estimated
9. Current not considered
10. Other

D-3 Course Does Not Leave Room for Maneuvering Required By Traffic/ Obstructions

1. Vessel's manuevering characteristics overestimated
2. Traffic density not considered
3. Traffic density underestimated

4. Coast Pilot/Sailing Directions not consulted, re obstructions
5. Extent of obstructions underestimated
6. Calculated risk
7. Course selected on the basis of saving time (e.g., as a means of meeting schedules, to reduce cost through reduction in running time, etc.)
8. Other

D-4 Course Does Not Provide Adequate Clearance for Poor Visibility Conditions:

1. Potential for poor visibility not considered
2. Potential for poor visibility underestimated
3. Calculated risk
4. Vessel's maneuvering characteristics overestimated
5. Required clearance for poor visibility conditions misjudged
6. Course selected on the basis of saving time (e.g., as a means of meeting schedules, to reduce cost through reduction in running time, etc.)
7. Other

D-5 Hazard Not Where It Is Thought To Be Due To Inadequate Marking/ Identification

1. Hazard incorrectly located on charts
2. Hazard inaccurately described in Coast Pilot/Sailing Directions
3. Hazard location incorrectly described in Local Notice to Mariners
4. Hazard marking incorrectly described in Charts/Light List/Coast Pilot/Local Notices to Mariners/Sailing Directions
5. Hazard markings confused with other markings
6. Hazard not adequately marked
7. Other

FIGURE D-7. ASSESSMENT OF LOP/POSITION LTA

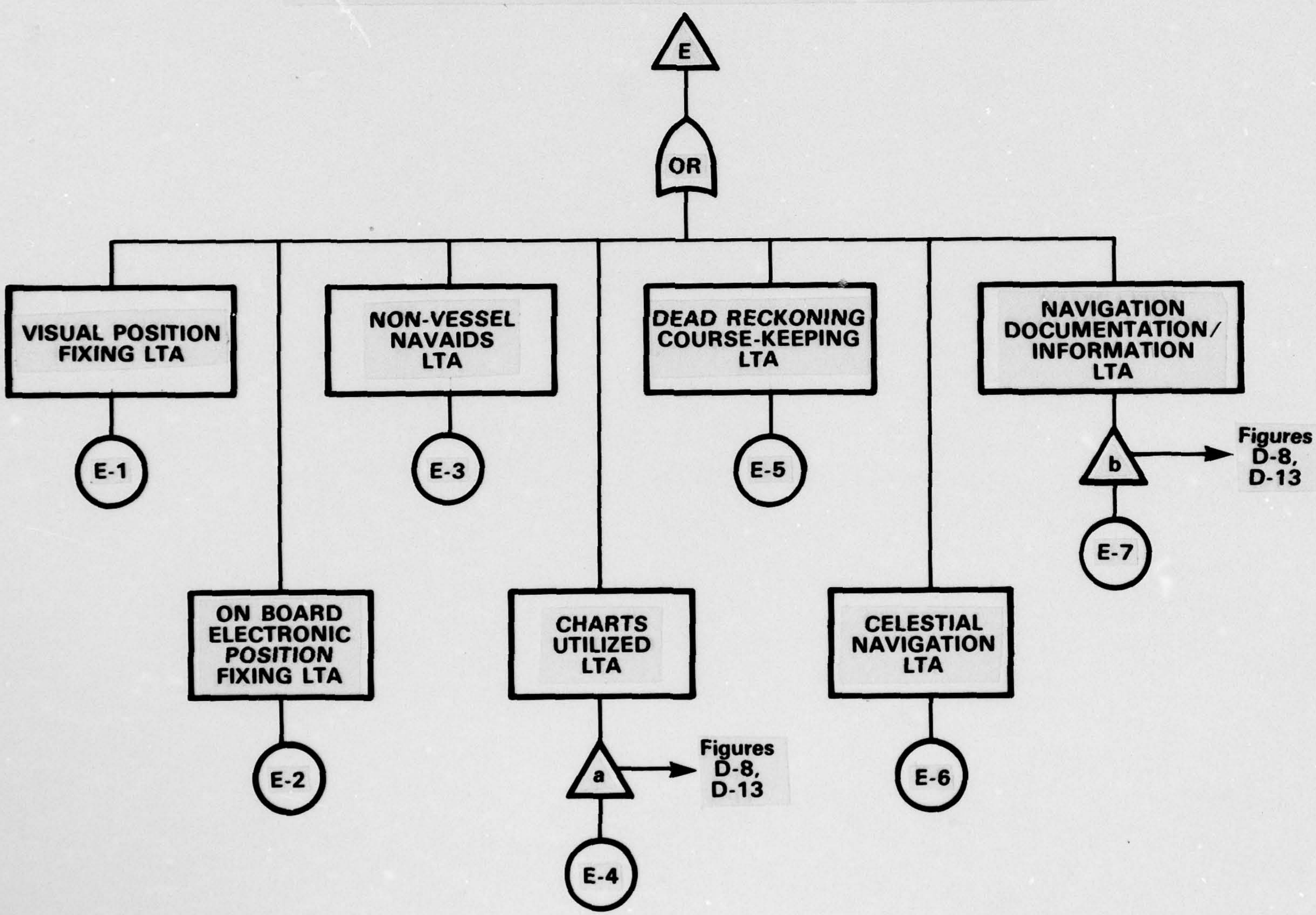

Figure D-7

Assessment of LOP/Position LTA

E-1 Visual Position Fixing LTA

1. Too infrequent
2. Insufficient information obtained
3. Fix "object" incorrectly identified
4. Fixes incorrectly plotted
5. Angle read incorrectly
6. Visibility obstructions due to vessel design
7. Pelorus out-of-adjustment
8. Inadequate fix-taking accuracy
9. Non-vessel, non-electronic navaids not optimally placed
10. Non-vessel, non-electronic navaid non-operational
11. Non-vessels, non-electronic navaids degraded (lights operating at reduced intensity, not rotating, etc.)
12. Other

E-2 On Board Electronic Position Fixing LTA

Includes: RDF/ADF
Loran
Omega
Decca
Fathometer
Satellite Navigation Equipment

Navaid Malfunctioning:

1. Navaid malfunctioning, repair not possible due to lack of spare parts/schematics
2. Navaid malfunctioning, repair not possible due to lack of skills
3. Navaid malfunction occurred too recently for repair to have been made
4. Navaid malfunctioning, repair not possible because unit not designed to be repaired at sea
5. Navaid accuracy degraded
6. Other

290

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Navaid Design LTA:

7. Navaid accuracy inadequate--design fault
8. Navaid display/controls cumbersome--lack of attention to optimum design layout
9. Range/resolution of navaid inadequate--design fault
10. Other

On-Board Navaid Operational Procedures LTA:

11. Electronic position fixes taken too infrequently
12. Fixes incorrectly plotted
13. Inadequate fix taking accuracy
14. Insufficient information obtained
15. Navaid data misinterpreted--lack of skills
16. Navaid data misinterpreted-carelessness
17. Navaid data misinterpreted--incompetence
18. Out-of-date navaid correction factors applied
19. Other

On-Board Navaid Provisions LTA:

20. Insufficient navaids provided
21. Up-to-date navaid correction factors not provided
22. Use of navaids difficult due to non-optimum location
23. Other

E-3 Non-Vessel Navaids LTA

Includes: Radio Beacons
Loran-C
Omega
Decca
Navigation Satellites

1. Navaid off-the-air; routine maintenance
2. Navaid off-the-air; equipment failure
3. Navaid coverage/range inadequate
4. Navaid accuracy degraded--design fault
5. Navaid accuracy degraded--environmental conditions
6. Navaid correction factors not available--dissemination of information LTA

7. Insufficient types of navaids provided
8. Other

E-4 Charts Utilized LTA

1. Charts out-of-date
2. Insufficient charts provided
3. Wrong scale chart used
4. Charts in error
5. Incorrect plotting procedures applied
6. Chart in poor physical condition
7. Chart not adequately consulted
8. Other

E-5 Dead Reckoning/Course Keeping LTA

1. Vessel speed misjudged -- lack of skills
2. Vessel speed misjudged -- skills not properly applied
3. Vessel speed misjudged -- equipment malfunction
4. Effects of steering errors not detected -- carelessness
5. Effects of steering errors not detected -- lack of skills
6 Compass misread, lack of skills
7. Compass misread, skills not properly applied
8. Inadequate attention to frequency of compass reading --lack of skills
9. Inadequate attention to frequency of compass reading --skills not properly applied
10. Compass malfunctioning
11. Compass incorrectly calibrated - negligence
12. DR estimates made too infrequently
13. DR estimates arrived at carelessly
14. Effect of current/wind not considered -- lack of skills
15. Effect of current/wind not considered -- skills not properly applied
16. Effect of current/wind considered inaccurately -- lack of skills
17. Effect of current/wind considered inaccurately -- skills not properly applied
18. Effects of steering errors not considered -- lack of skills
19. Effects of steering errors not considered -- skills not properly applied
20. Incorrect variation/deviation applied -- lack of skills

21. Incorrect variation/deviation applied -- skills not properly applied
22. DR position plotted incorrectly -- lack of skills
23. Other

E-6 Celestial Navigation LTA

1. Sextant/chronometer in error
2. Sights taken too infrequently
3. Errors in sight reduction
4. Errors in sight taking procedures
5. Sight reduction data not provided
6. Sight reduction data out-of-date
7. Other

E-7 Navigation Documentation/Information LTA

Includes: Light List
Coast Pilot
Local Notices to Mariners, printed and broadcast, Coast Guard and Defense Mapping Agency
Sailing Directions

1. Inadequate documentation/information consulted
2. Inadequate documentation/information provided/available
3. Documentation/information misinterpreted
4. Scope/coverage/content of documentation/information inadequate
5. Documentation/information in error
6. Documentation/information update releases too infrequent
7. Method of update releases LTA
8. Inadequate monitoring for update releases
9. Other

FIGURE D-8. ASSESSMENT OF HAZARDS/OBSTRUCTIONS LTA

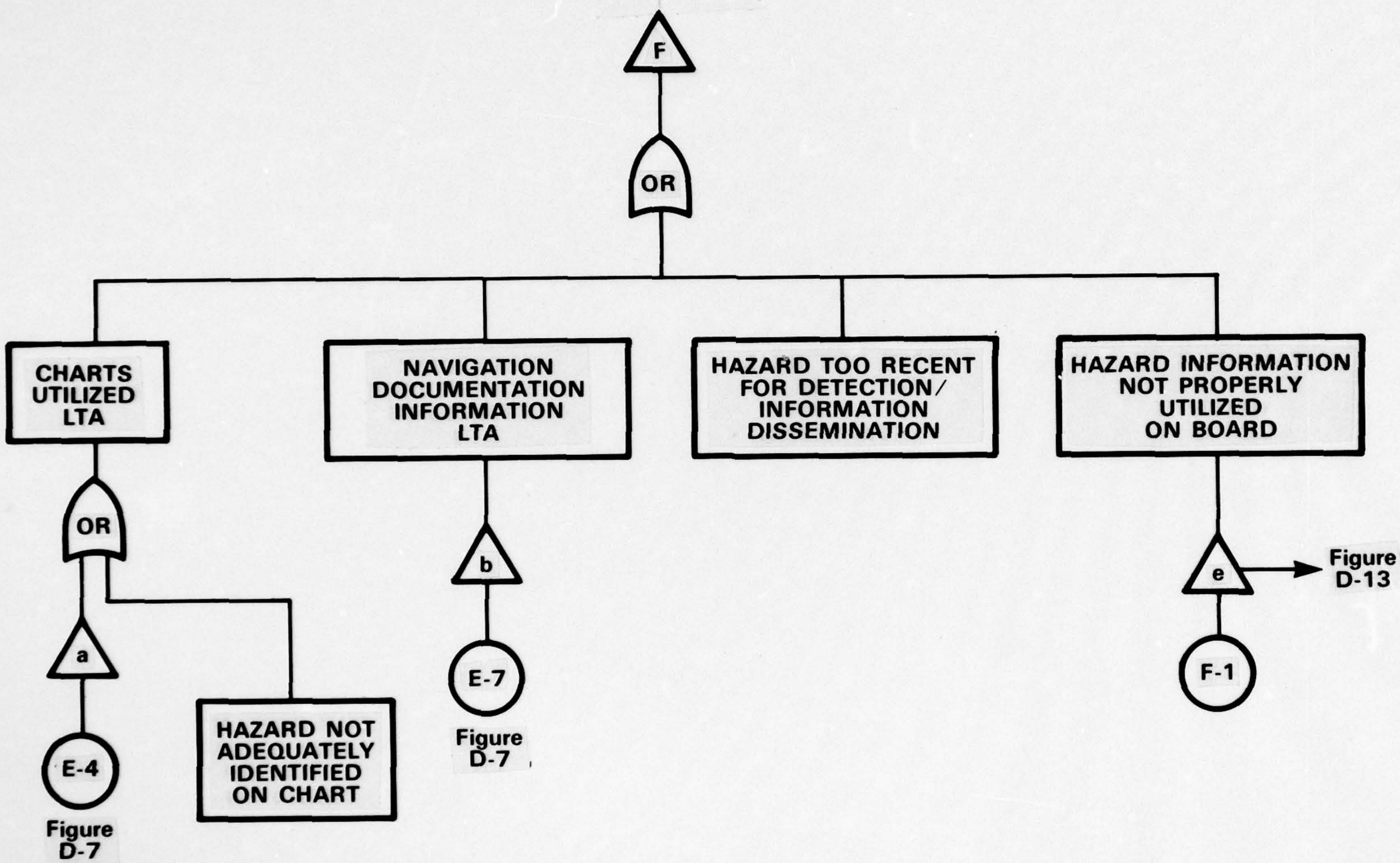

Figure D-8

Assessment of Hazards/Obstructions LTA

F-1 <u>Hazard Information Not Properly Utilized On Board</u>

1. Inadequate information conveyed at change-of-watch
2. Inadequate information exchanged among watch-standers
3. Information received on board but not relayed adequately
4. Information disregarded -- carelessness
5. Information disregarded -- negligence
6. Information disregarded -- incompetence
7. Information disregarded -- insubordination
8. Other

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DEEPWATER PORTS APPROACH/EXIT HAZARD AND RISK ASSESSMENT.(U)

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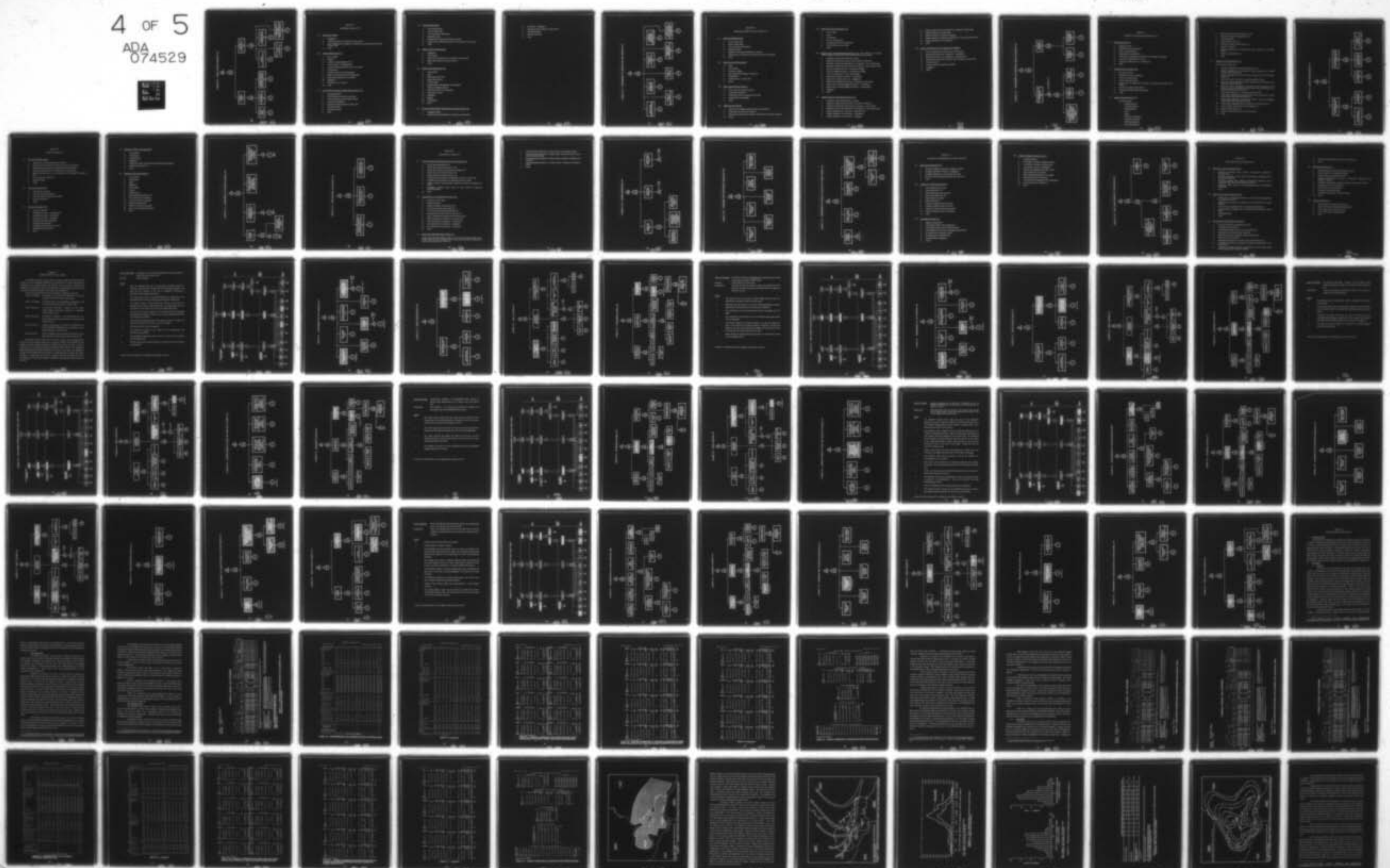


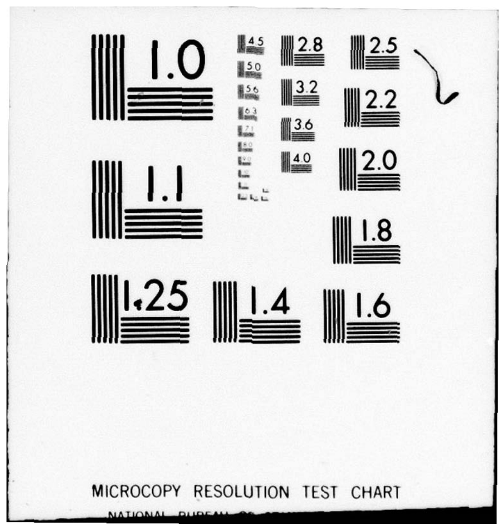
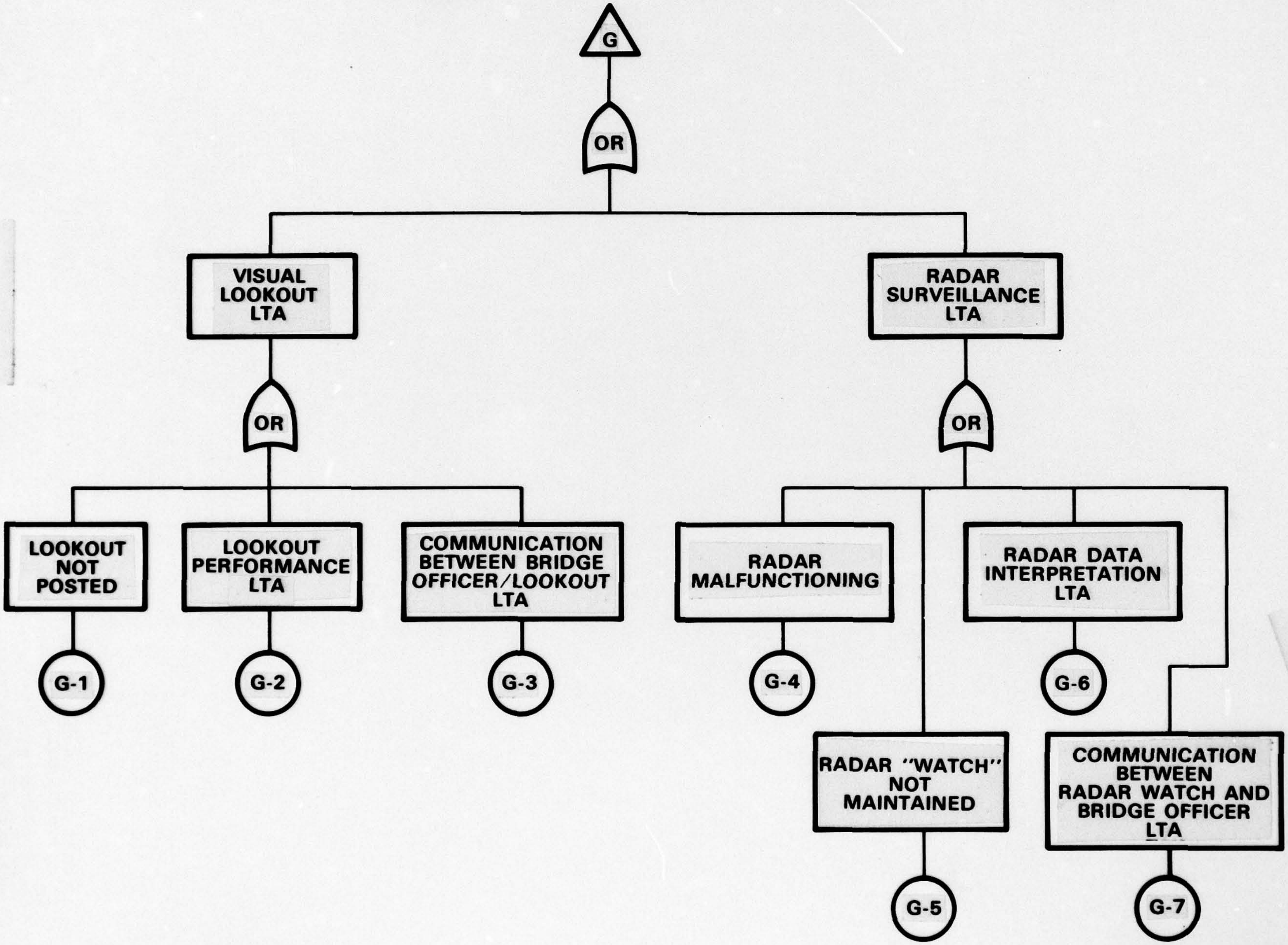

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART

FIGURE D-9. VISUAL/RADAR LOOKOUT LTA



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296

Figure D-9

Visual/Radar Lookout LTA

G-1 Lookout Not Posted

1. Negligence
2. Lookout posted, but temporarily leaves his post
3. Short handed due to temporary overload (e.g., watchstander(s) diverted to other task)
4. Other

G-2 Lookout Performance LTA

1. Poor eyesight
2. Fatigue
3. Lookout training/experience LTA
4. Under influence of drugs/alcohol
5. Lookout's attention diverted due to other tasks
6. Incompetence
7. Lookout station has visual blockage
8. Night vision impaired by surrounding lights
9. Night vision adaptation not complete
10. Negligence
11. Discomfort due to weather
12. Other

G-3 Communication Between Bridge Officer/Lookout LTA

1. Language problem
2. Communications devices not provided
3. Communications devices malfunctioning
4. Inattention-negligence
5. Inattention due to pressure of other tasks
6. Misunderstanding
7. Personal animosity
8. Other

G-4 Radar Malfunctioning

1. Lack of spare parts
2. Lack of repair skills
3. Lack of periodic maintenance
4. Equipment abuse
5. Malfunction not detected; difficult to detect
6. Malfunction not detected; occurred too recently to be corrected
7. Other

G-5 Radar "Watch" Not Maintained

1. Negligence
2. Short-handed
3. Radar watch maintained, but temporarily discontinued
4. Radar watch distracted by other duties
5. Other

G-6 Radar Data Interpretation LTA

1. Lack of skills
2. Haste
3. Data presentation LTA
4. Range selection LTA
5. Poor eye sight
6. Targets plotted incompletely or infrequently
7. Targets erroneously plotted
8. Information taken too infrequently
9. Information in error
10. Negligence
11. Fatigue
12. Carelessness
13. Other

G-7 Communication Between Radar Watch and Bridge Officer LTA

1. Language problem
2. Equipment location/bridge layout impairs communication

3. Inattention - negligence
4. Inattention due to pressure of other tasks
5. Misunderstanding
6. Personal animosity
7. Other

FIGURE D-10. ASSESSMENT OF SPEED OVER THE GROUND LTA

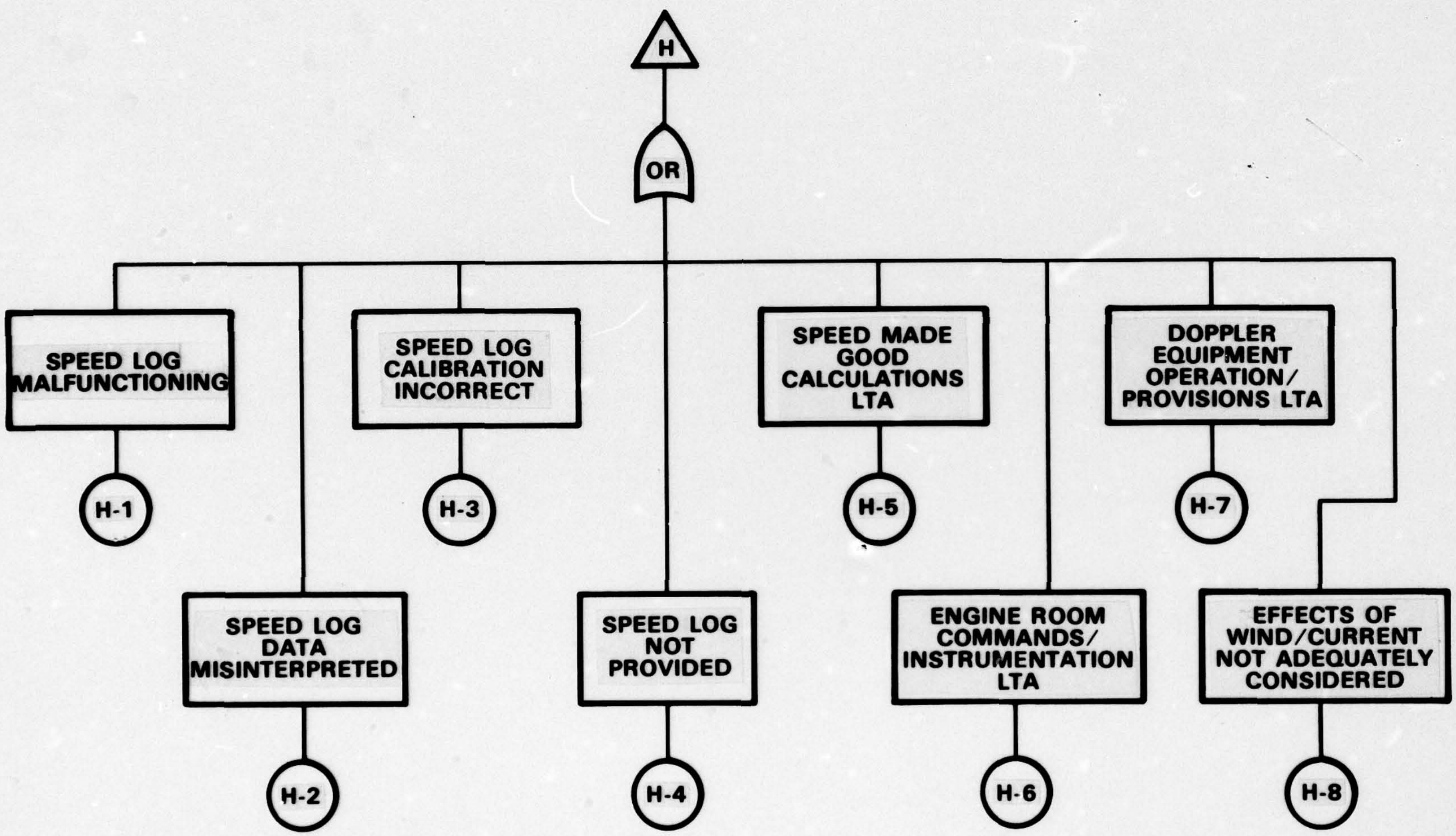

Figure D-10

Assessment of Speed-Over-The-Ground LTA

H-1 Speed Log Malfunctioning

1. Lack of spare parts
2. Lack of repair skills
3. Lack of periodic maintenance
4. Equipment abuse
5. Malfunction not detected; difficult to detect
6. Malfunction not detected, occurred too recently for detection
7. Other

H-2 Speed Log Data Misinterpreted

1. Haste
2. Lack of skills
3. Erroneous reading
4. Data presentation/display not optimum
5. Carelessness
6. Inattention due to other tasks
7. Other

H-3 Speed Log Calibration Incorrect

1. Lack of periodic calibration check
2. Calibrated erroneously
3. Calibration factors transcribed incorrectly
4. Calibrations too infrequent
5. Other

H-4 Speed Log Not Provided

1. Speed log not thought necessary when vessel outfitted
2. Speed log removed and not replaced
3. Speed log not provided on vessels of a given type as a matter of policy
4. Other

H-5 Speed Made Good Calculations LTA

1. Lack of skills
2. Haste
3. Carelessness
4. Error in computations
5. Calculations made too infrequently
6. Inattention due to other tasks
7. Other

H-6 Engine Room Commands/Instrumentation LTA (for instance, the bridge "thinks" engines are slow astern when actually they are half-astern)

1. Equipment malfunction; difficult to detect
2. Equipment malfunction; occurred too recently for detection
3. Equipment malfunction detected but not repaired -- lack of spare parts
4. Equipment malfunction detected but not repaired -- lack of repair skills
5. Incorrect telegraph setting -- carelessness (bridge)
6. Incorrect telegraph setting -- incompetence (bridge)
7. Lack of attention due to other tasks (bridge)
8. Engine room response incorrect -- carelessness
9. Engine room response incorrect -- negligence
10. Engine room response incorrect due to pressure of other tasks
11. Engine room commands logged incorrectly -- carelessness
12. Engine room commands logged incorrectly -- incompetence
13. Negligence
14. Other

H-7 Doppler Equipment Operation/Provisions LTA

1. Equipment malfunctions;difficult to detect
2. Equipment malfunction; occurred too recently for detection
3. Equipment malfunction detected but not repaired -- lack of skills
4. Equipment malfunction detected but not repaired -- lack of spare parts
5. Doppler equipment not monitored -- calculated risk
6. Doppler equipment not monitored -- carelessness
7. Doppler equipment not monitored -- negligence

8. Doppler equipment not monitored due to pressure of other tasks
9. Doppler equipment misread; haste
10. Doppler equipment misread; carelessness
11. Doppler equipment reading not accurate due to bottom characteristics
12. Doppler equipment out of calibration
13. Other

H-8 <u>Effects of Wind/Current Not Adequately Considered</u>

1. Lack of adequate information on the wind/currents
2. Wind/current effects not considered -- carelessness
3. Wind/current effects not considered -- calculated risk
4. Wind/current effects not considered due to pressure of other tasks
5. Unusual currents
6. Current effects erroneously considered
7. Negligence
8. Other

FIGURE D-11. ASSESSMENT OF APPROACH ANGLE/DISTANCE LTA

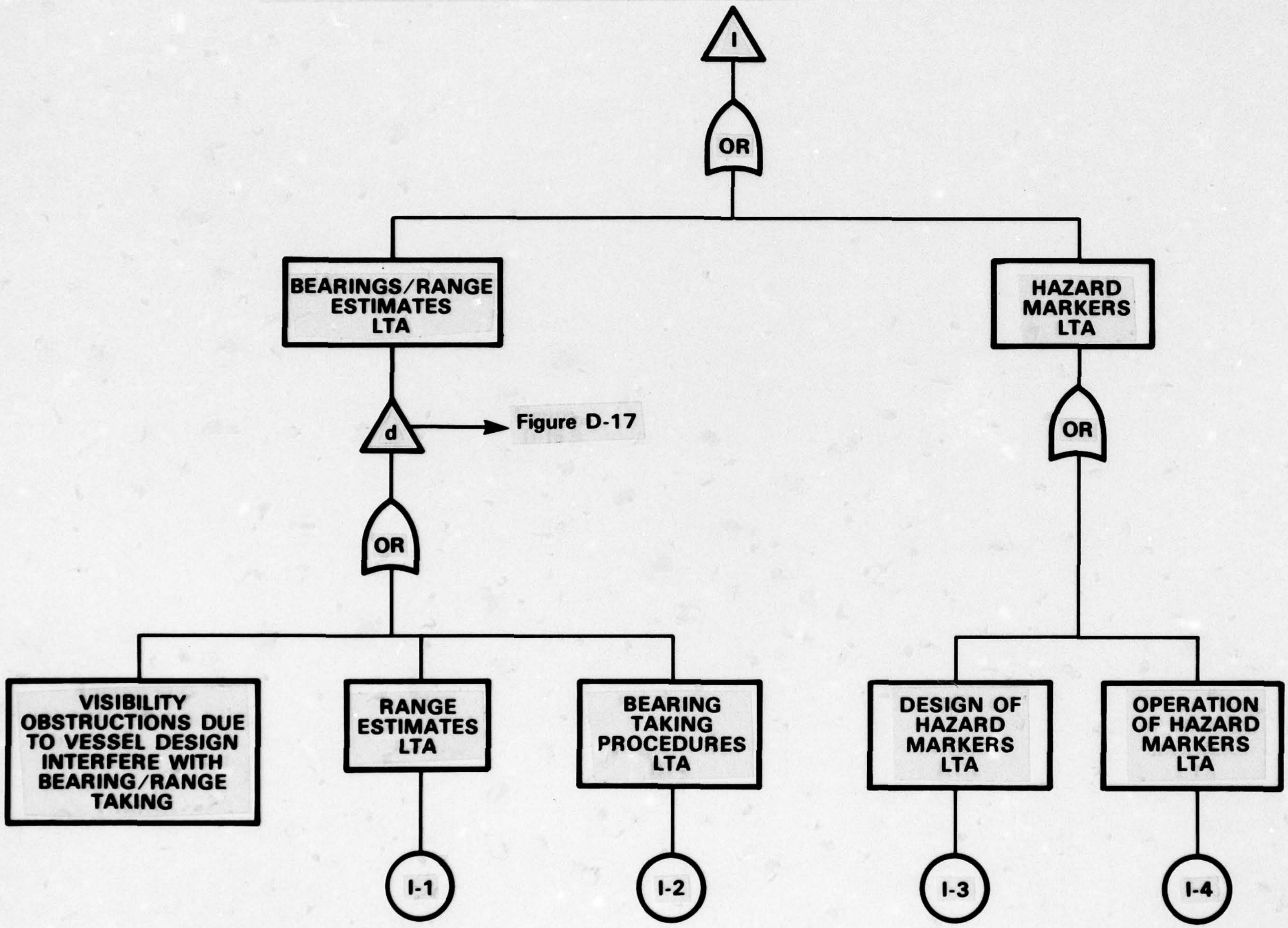

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Figure D-11

Assessment of Approach Angle/Distance LTA

I-1 Range Estimates LTA

1. Ranges not taken
2. Ranges taken too infrequently
3. Error in range estimate
4. Range lights misinterpreted
5. Vessel size not adquately considered in estimating closing angle
6. Inaccurate range estimate -- haste
7. Inaccurate range estimate -- carelessness
8. Other

I-2 Bearing-Taking Procedures LTA

1. Bearings not taken
2. Bearings taken too infrequently
3. Error in bearing reading
4. Error in bearing charting
5. Vessel size not adequately considered in determining distance from hazard
6. Inaccurate bearing taking--haste
7. Inaccurate bearing taking--carelessness
8. Other

I-3 Design of Hazard Markers LTA

Hazards include:

- Drilling platforms
- Submerged objects
- Floating Objects
- Reefs
- Shoals
- DWP Control Platform
- Vessels in Anchorage
- DWP Mooring Bouys
- Jetties/Breakwaters

1. Marker light visibility coverage restricted
2. Electronic marker coverage restricted
3. Sound signals LTA
4. Light characteristics LTA
5. Electronic marker characteristics LTA
6. Hazard not marked
7. Hazard markings can be confused with other markings or with background
8. Marker missing/off-station
9. Other

I-4 Operation of Hazard Markers LTA

For hazards, see above list.

1. Light(s) extinguished; completed equipment failure
2. Light(s) degraded; partial equipment failure (operating at reduced intensity, not rotating, etc.)
3. Light(s) degraded; environmental effects (obscured by salt, bird droppings, etc.)
4. Electronic marker off-the-air; complete equipment failure
5. Electronic marker degraded; partial equipment failure (reduced range, altered characteristics, etc.)
6. Electronic marker degraded; environmental effects (interference from natural sources, e.g., electrical storms, from man-made sources, e.g., electronic warfare exercises, etc.)
7. Sound signal inoperative -- complete equipment failure
8. Sound signal degraded; partial equipment failure (operating at reduced sound level, altered characteristics, etc.)
9. Sound signal degraded; environmental effects (altered propagation characteristic due to fog, for instance)
10. Visual markers degraded (rusted, rotted away, sun bleached, etc.)
11. Visual markers obscured (salt, bird droppings, etc.)
12. Hazard markers destroyed
13. Marker turned off/not turned on; personnel error
14. Other

FIGURE D-12. DEPTH SURVEILLANCE LTA

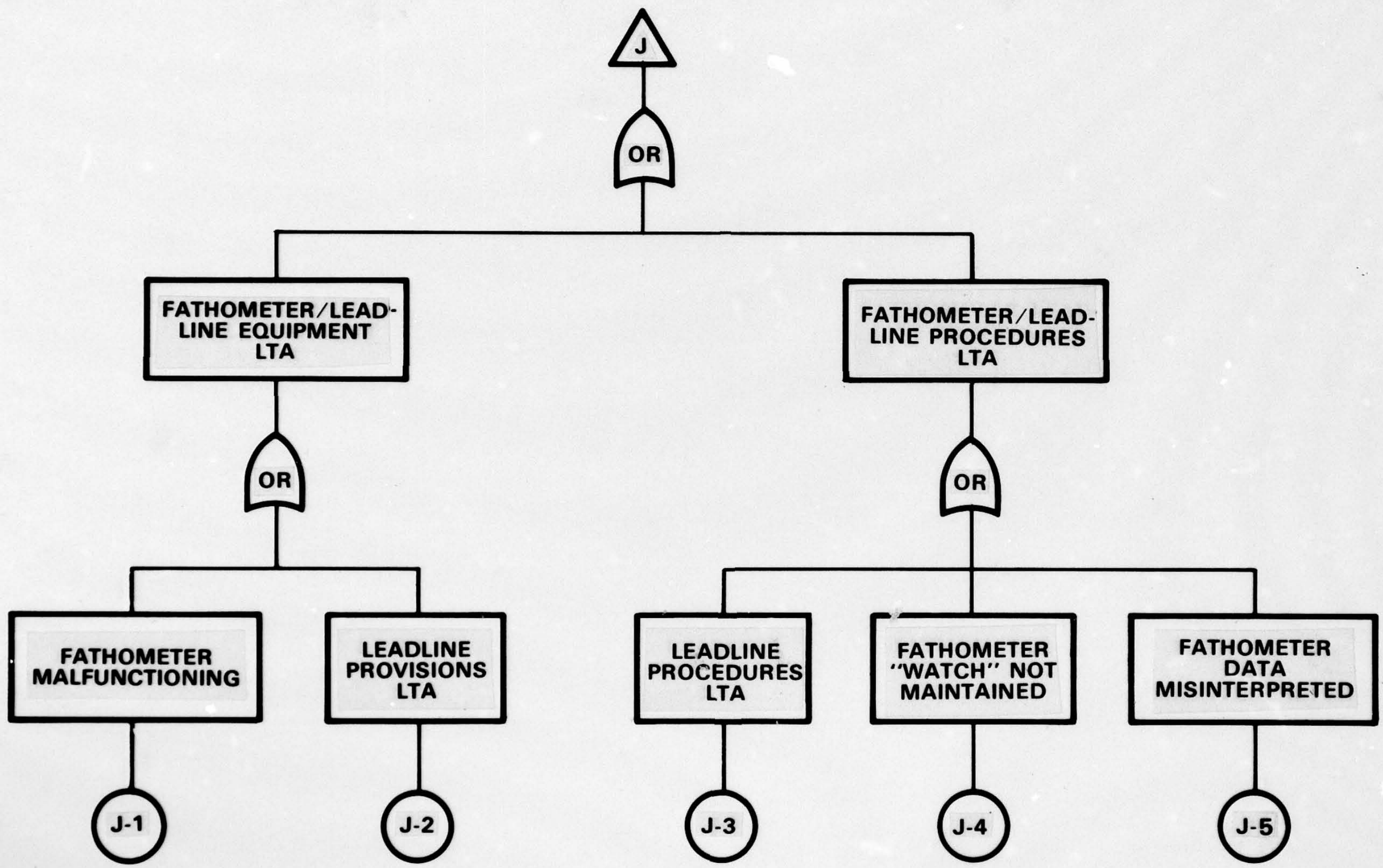

Figure D-12

Depth Surveillance LTA

J-1 Fathometer Malfunctioning

1. Malfunction not detected; difficult to detect
2. Malfunction not detected; occurred too recently for detection
3. Malfunction detected but not repaired; lack of repair skills
4. Malfunction detected but not repaired; lack of spare parts
5. Malfunction detected but not repaired; unit not designed for repair at sea
6. Lack of periodic maintenance
7. Equipment abuse
8. Other

J-2 Lead Line Provisions LTA

1. Lead line not provided
2. Lead line deteriorated/parted
3. Lead line markers deteriorated/missing
4. Lead line length LTA
5. Other

J-3 Lead Line Procedures LTA

1. Lead line misplaced
2. Soundings not taken -- calculated risk
3. Soundings not taken -- carelessness
4. Soundings not taken -- negligence
5. Soundings taken too infrequently
6. Soundings misinterpreted
7. Soundings communicated incorrectly
8. Soundings taken incorrectly
9. Other

J-4 Fathometer "Watch" Not Maintained

1. Short-handed
2. Carelessness
3. Calculated risk
4. Negligence
5. Fathometer watch maintained but temporarily discontinued
6. Fathometer location LTA
7. Other

J-5 Fathometer Data Misinterpreted

1. Lack of skills
2. Carelessness
3. Haste
4. Negligence
5. Poor eyesight
6. Fatigue
7. Drugs/alcohol
8. Data presentation/display LTA
9. Correction factors not posted
10. Correction factors not applied
11. Improper scale selected
12. Depths on charts not consulted
13. Data not communicated correctly
14. Other

FIGURE D-13. ASSESSMENT OF HAZARDS/SHOALS LTA

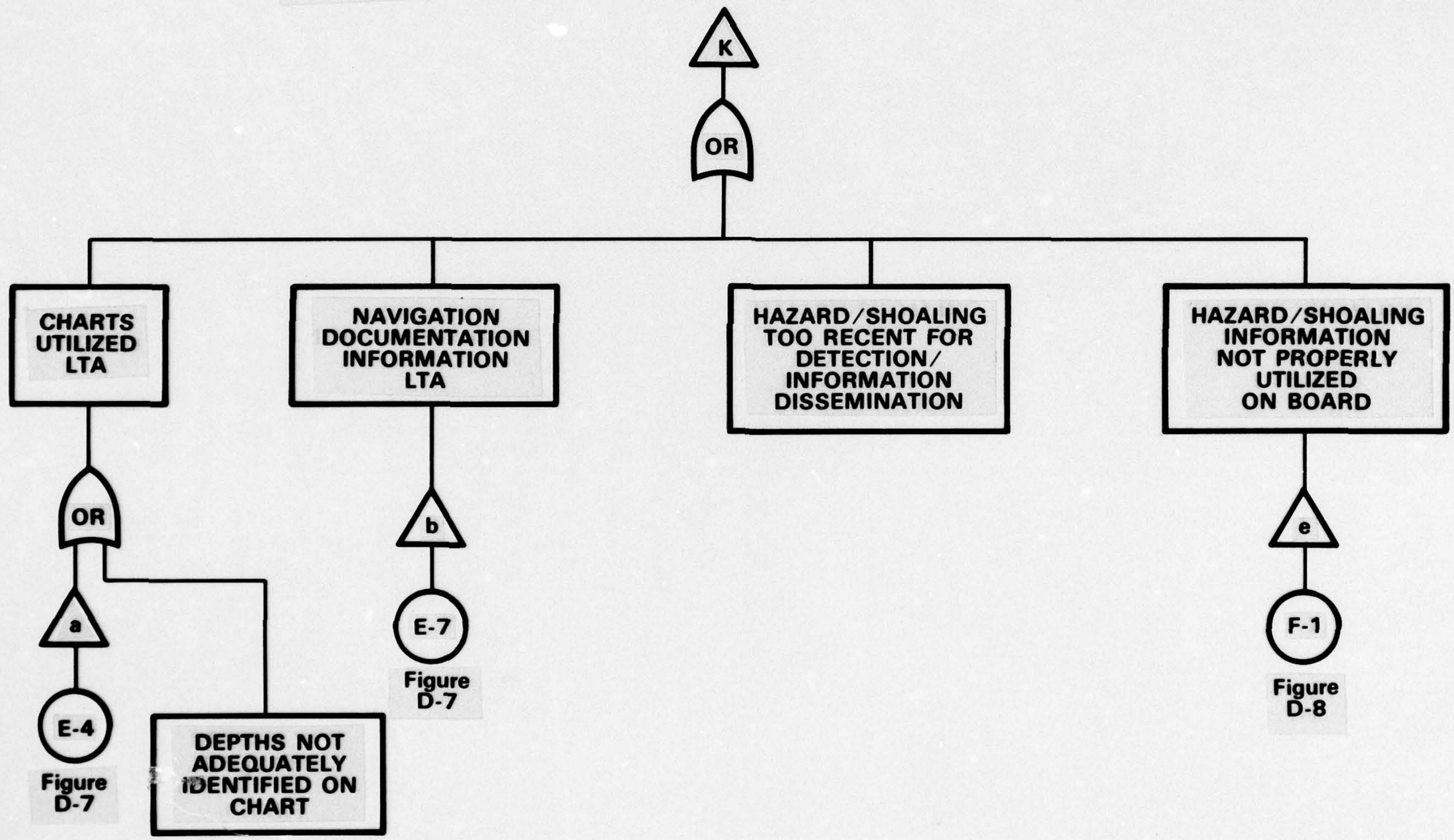

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Figure D-14

FIGURE D-14. PRECAUTIONS FOR TRAFFIC LTA

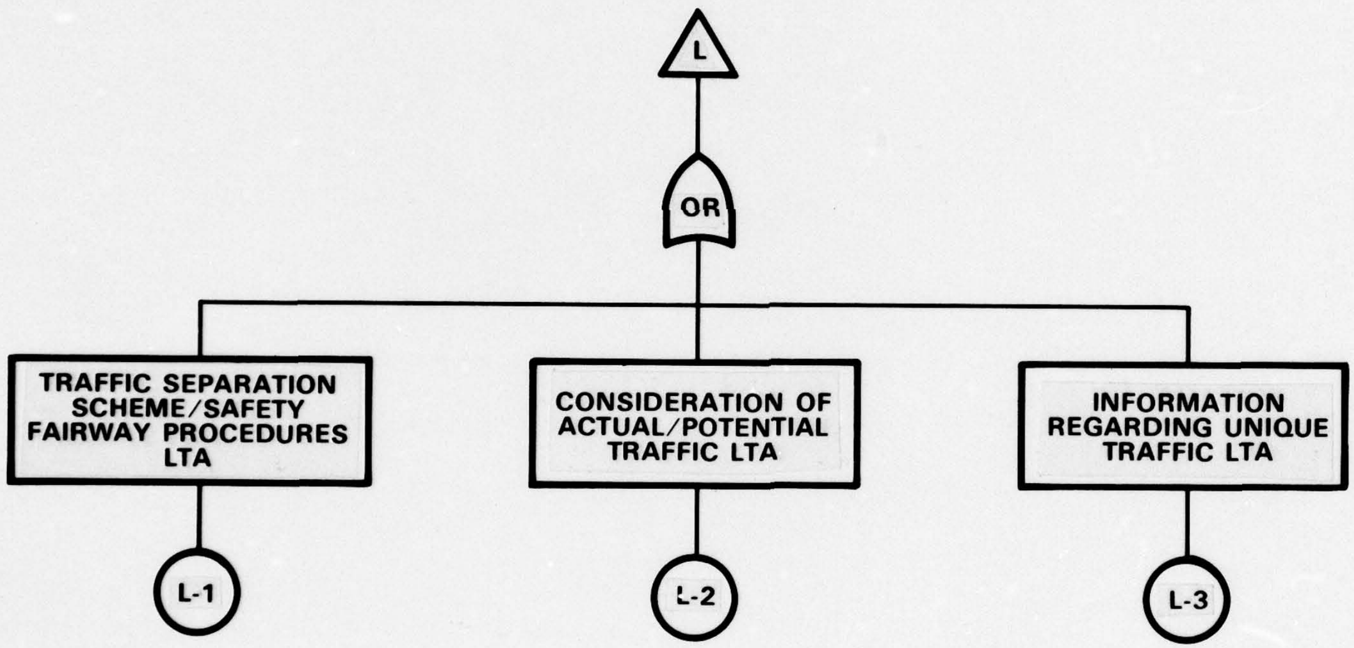

Figure D-14

Precautions for Traffic LTA

L-1 Traffic Separation Scheme/Safety Fairway Procedures LTA

1. Marker buoys positions(s) LTA
2. Marker buoy visual characteristics LTA
3. Marker buoy electronic characteristics/range LTA
4. Marker buoy sound characteristics LTA
5. Design requires excessive manuevering
6. TSS/safety fairway details not adequately covered in Coast Pilot
7. TSS/safety fairway details not adequately shown on charts
8. Widths of safety fairways/traffic separation scheme not adequate for traffic
9. Inadequate advanced notices given in Local Notice to Mariners, printed/broadcast
10. Other

L-2 Consideration of Actual/Potential Traffic LTA

1. Vessel left on auto-pilot
2. Speed not prudent
3. Bridge-to-bridge communication LTA
4. Charts not consulted concerning TSS
5. Coast Pilot not consulted concerning TSS
6. Consideration of other vessel's intentions LTA
7. Other vessel/object interferes with intended course
8. Other vessel does not make her intentions clear
9. TSS requirements not observed -- carelessness
10. TSS requirements not observed -- negligence
11. TSS requirements not observed -- intentional
12. Other

L-3 Information Regarding Unique Traffic LTA

Unique traffic includes floating objects with restricted maneuverability such as drill rigs under tow, fishing vessel with long trawls, petroleum exploration vessels towing long seismic cables, etc.

1. Information/documentation on unique traffic not provided on board.
2. Information/documentation on unique traffic received on board but not communicated to bridge
3. Information/documentation on unique traffic available to bridge but not consulted
4. Information/documentation on unique traffic consulted but misinterpreted
5. Other

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FIGURE D-15. CLOSING MANEUVER LTA

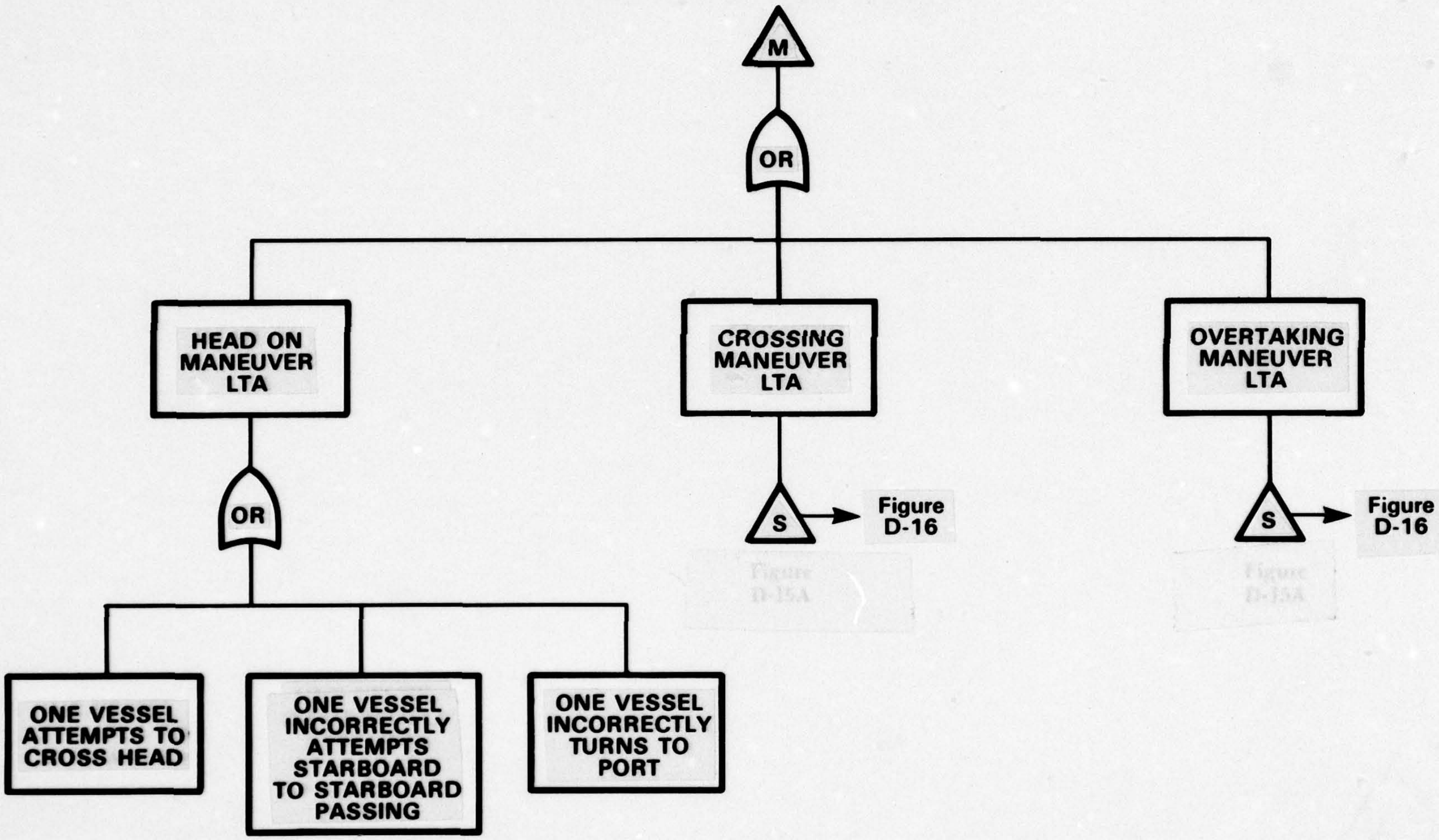

FIGURE D-16. CROSSING AND OVERTAKING MANEUVER LTA

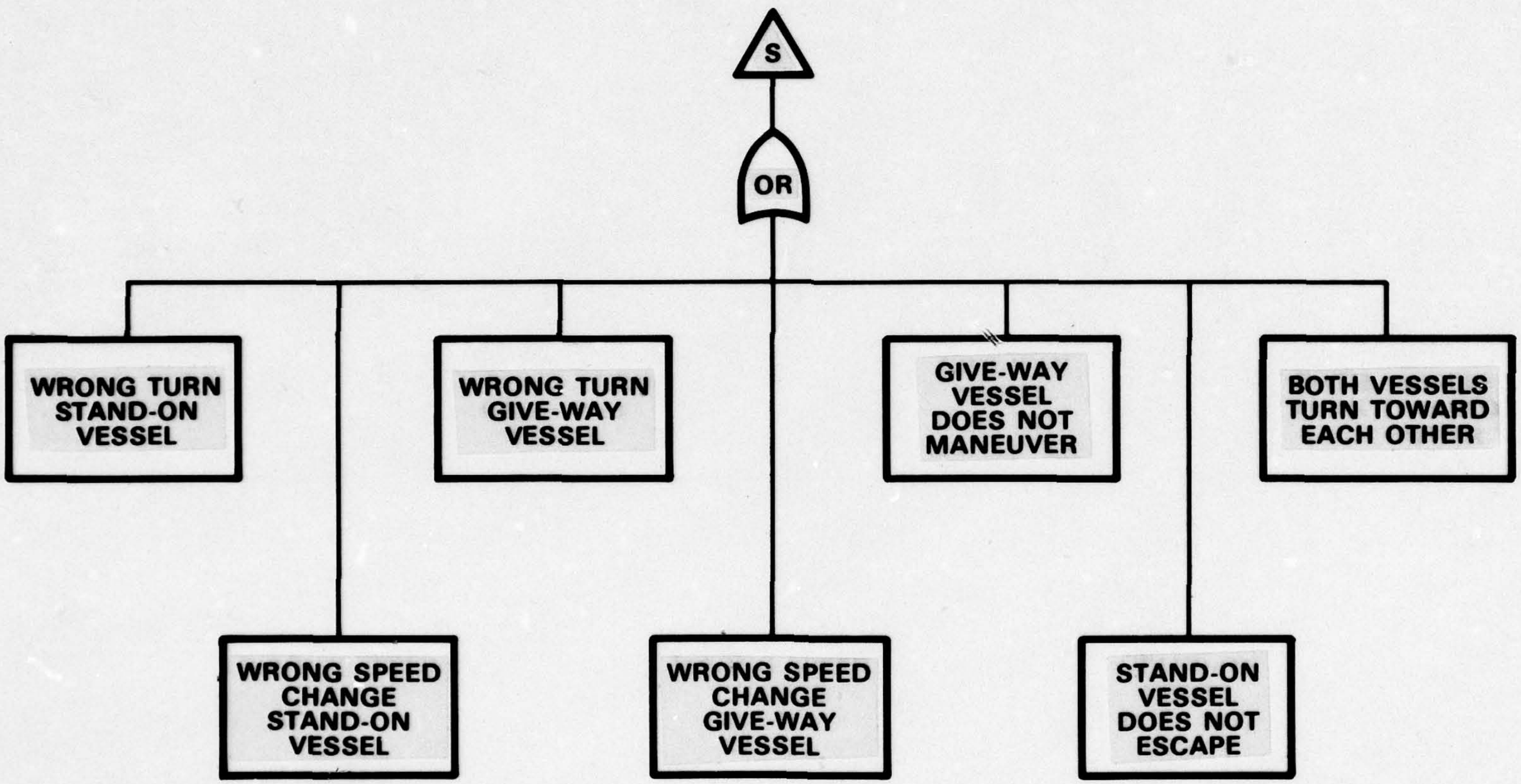

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FIGURE D-17. ASSESSMENT OF ANGLE/DISTANCE TO OTHER VESSEL LTA

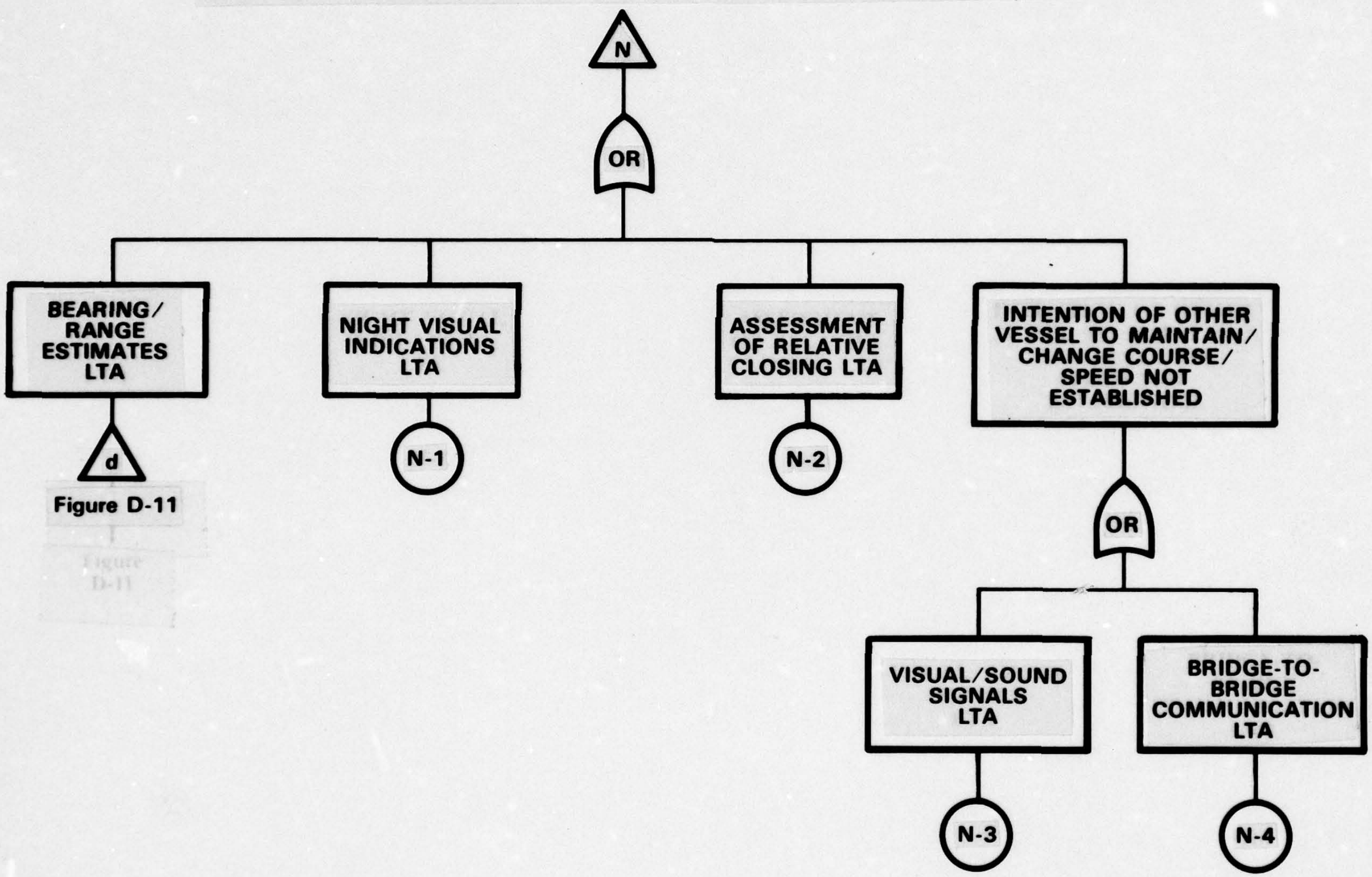

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Figure D-17

Assessment of Angle/Distance to Other Vessel LTA

N-1 Night Visual Indications LTA

1. Navigation light(s) extinguished--equipment failure
2. Navigation light(s) not turned on--negligence
3. Navigation light(s) not in accordance with rules
4. Navigation light(s) degraded (broken lens, dirty, etc.)
5. Other

N-2 Assessment of Relative Motion LTA

1. Visual assessment not made
2. Visual assessment LTA
3. Maneuvering board plot not made
4. Maneuvering board plot LTA
5. Radar PPI plot not made
6. Radar PPI plot LTA
7. Collision avoidance system not used
8. Collision avoidance system used LTA
9. Collision avoidance system not provided
10. Collision avidance system not operable
11. Other

N-3 Visual/Sound Signals LTA

1. Signals misinterpreted
2. Confusing/improper sound signals given
3. Confusing/improper course change indicated
4. Sound signals not heard due to propagation phenomena
5. No signals given--equipment failure
6. No signals given--calculated risk
7. No signals given--negligence
8. Other

N-4 <u>Bridge-to-Bridge Communication LTA</u>

1. Language problem
2. No attempt to contact--equipment failure
3. No attempt to contact--calculated risk
4. No attempt to contact---negligence
5. Channel not available due to other traffic
6. Other vessel does not respond
7. Radio telephone equipment not provided
8. Operating procedures confusing
9. Communications established with wrong vessel
10. Communications not understood
11. Other

FIGURE D-18. DWP CLOSE PROXIMITY OPERATIONS LTA

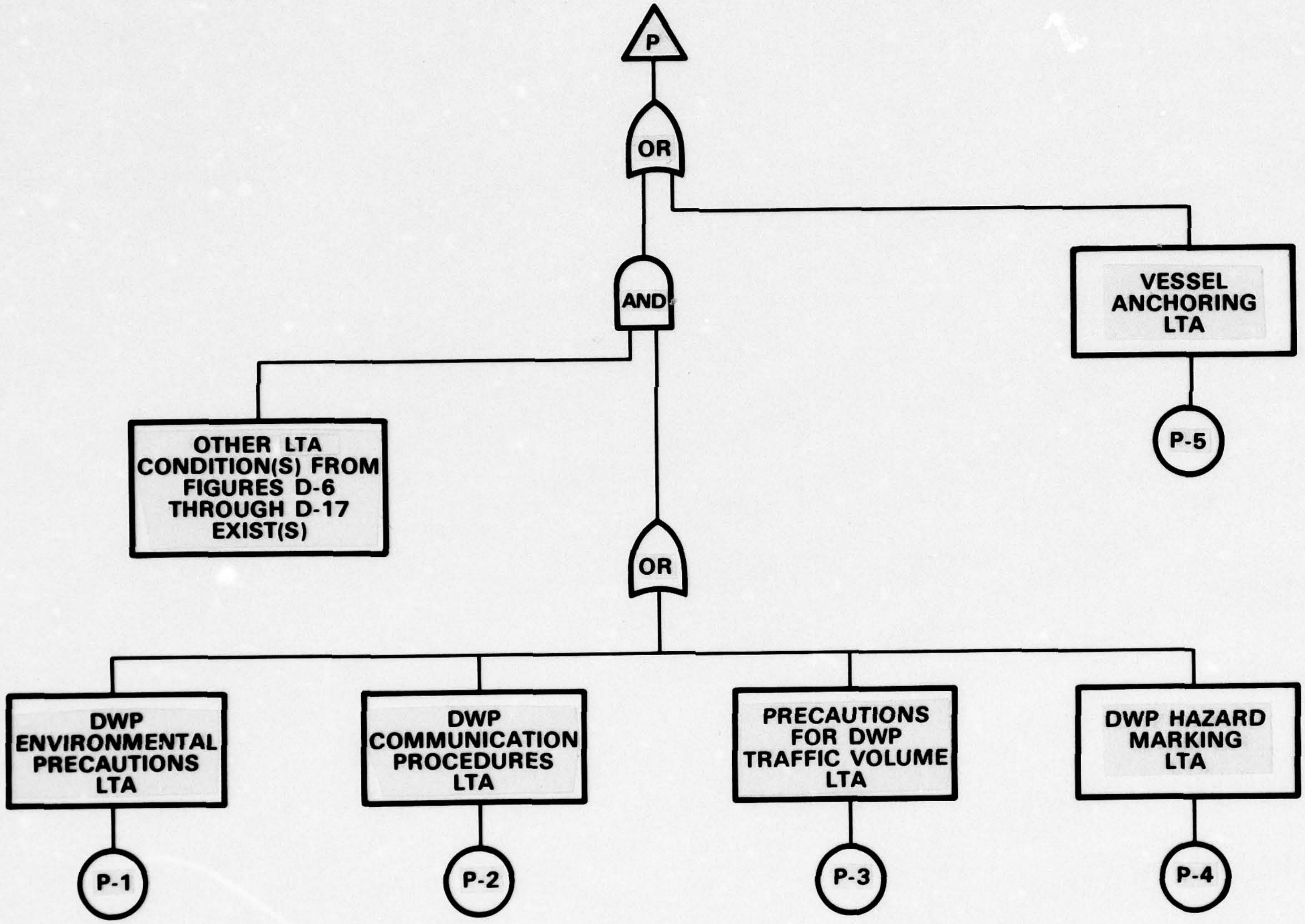

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Figure D-18

DWP Close Proximity Operations LTA

P-1 DWP Environmental Precautions LTA

1. Entry/exit attempted under extreme environmental conditions---calculated risk
2. Entry/Exit attempted under extreme environmental conditions due to unpredicted conditions
3. Entry/Exit allowed under adverse environmental conditions due to inadequate DWP Operations guidelines/procedures
4. Inadequate DWP system for obtaining/disseminating meteorological information
5. Other

P-2 DWP Communications Procedures LTA

1. Vessel does not advise control platform of its ETA, thus placing strains on capabilities at arrival
2. Vessel does not proceed in accordance with instructions from control platform
3. Communications inadequate due to malfunctioning equipment
4. Communications inadequate due to inadequate communications system design
5. Language problem
6. Other

P-3 Precautions for DWP Traffic Volume LTA

1. Queuing procedures not adequately planned
2. Anchorage area undersized
3. Anchorage area layout requires critical maneuvering
4. Mooring buoy maneuvering area undersized
5. Speed restrictions not adequately established/enforced
6. DWP safety zone undersized
7. Inadequate provisions for non-DWP traffic in DWP safety zone
8. Inadequate restrictions on allowable, simultaneous maneuvering of 2 or more VLCC's
9. Inadequate warnings signalling arrival/departure of VLCC (e.g., vessel's whistle signals alone not always audible)

10. DWP entrance/exit requires excessive maneuvering
11. Other

P-4 DWP Hazard Markings LTA

1. Shoreward extent of DWP not adequately marked
2. Control Platform not adequately marked
3. Mooring buoys not adequately marked
4. Adequate consideration not given to "electronic" marking for poor visibility conditions
5. Adequate consideration not given to visibility restrictions of VLCC's
6. Anchorage area not well delineated
7. Traffic lanes not well delineated
8. Inadequate sound signal range
9. Inadequate maintenance of hazard markings
10. Other

P-5 Vessel Anchoring LTA

1. Vessel adrift due to ground tackle failure
2. Vessel adrift due to inadequate holding ground
3. Other vessel fouls VLCC anchor chain
4. VLCC anchor fouls in pipeline/hoses
5. Other

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Appendix E

AFTER-THE-FACT FAULT TREES

To validate the fault trees, a sample of actual accident case histories were tested in the trees developed in appendix D to determine "fit." While some degree of tautology may be involved (these case histories were also used in evaluating the "anatomy of an accident"), there was no difficulty in fitting the details of the actual accident into scenarios provided in the fault trees of appendix D.

There are six case histories that are reviewed this appendix. They are:

Case 1, Grounding:	Grounding of the SS HILLYER BROWN at Cold Bay, Alaska on 7 March 1973 with no loss of life.
Case 2, Grounding:	SS OCEAN EAGLE (LI) grounding and breaking up with no loss of life, San Juan Harbor, 3 March 1968.
Case 3, Ramming:	SS AFRICAN NEPTUNE: Collision with the Sidney Lanier Bridge at Brunswick, Georgia on 7 November 1972 with loss of life.
Case 4, Ramming:	SS EDGAR M. QUEENY - S/T CORINTHOS (LI): Collision at Marcus Hook, Pennsylvania on 31 January 1975 with loss of life.
Case 5, Collision:	Collision involving the SS ARIZONA STANDARD and the SS OREGON STANDARD at the entrance to San Francisco Bay on 18 January 1978.
Case 6, Collision:	SS KEY TRADER and SS BAUNE (NO) collision in the Mississippi River on 18 January 1974 with loss of life.

The format used for each case is the same, namely, the first page briefly states the type of accident followed by a series of "notes" which describe the key sequence of events (causes and effects) outlining the accident as given in the U.S. Coast Guard or the National Transportation Safety Board reviews. The subsequent pages following each case history depicts the key fault tree charts from appendix D and key events (shaded) that are pertinent in describing each of these case history accidents. In each case, the fault tree identifies correctly the cause and effect relationship which lead to the accident, validating in a general sense the structure of the trees.

Case 1, Grounding: Grounding of the SS HILLYER BROWN at Cold Bay, Alaska on 7 March 1973 with no loss of life.

Weather: 7 miles visibility.

Notes*

1 Buoy was missing; when this was announced on broadcast Notice to Mariners, the vessel was at anchor and not monitoring broadcasts. The pilot was also unaware of this due to inadequate monitoring of broadcasts by the pilotage association.

2 The Coast Guard did not continue mentioning the missing buoy in its broadcast Notice to Mariners because policy does not require this.

3 The inherent delay in disseminating the written, Local Notice to Mariners by the Coast Guard meant that the missing buoy was not mentioned in the written notices until after subject grounding.

4 The pilot was relying so heavily on the missing buoy (not acceptable practice) that he failed to effectively use other available navaids that were sufficiently charted.

5 The master was relying entirely on the pilot and failed to monitor the vessel's movements to insure that it was not in danger.

6 Fathometer watch was not maintained.

7 The potential criticality of the situation was not appreciated, and therefore not reassessed.

8 No contingency orders were given since the criticality of the situation was not appreciated.

9 Without warning, the vessel grounded on reef-like rocks and its bottom was breached.

* Refer to circled numbers on tree diagram that follow for case 1.

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE

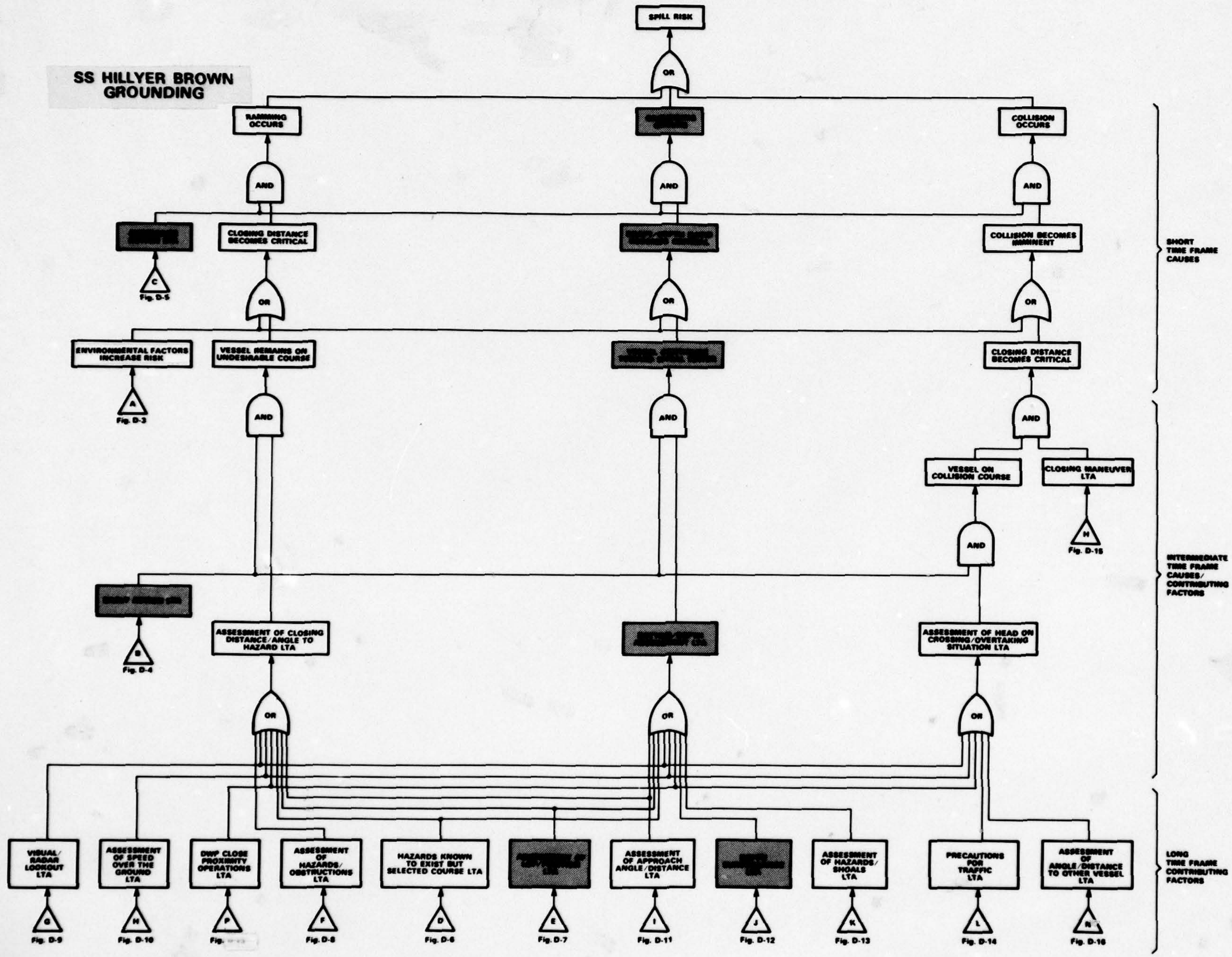


FIGURE D-7. ASSESSMENT OF LOP/POSITION LTA

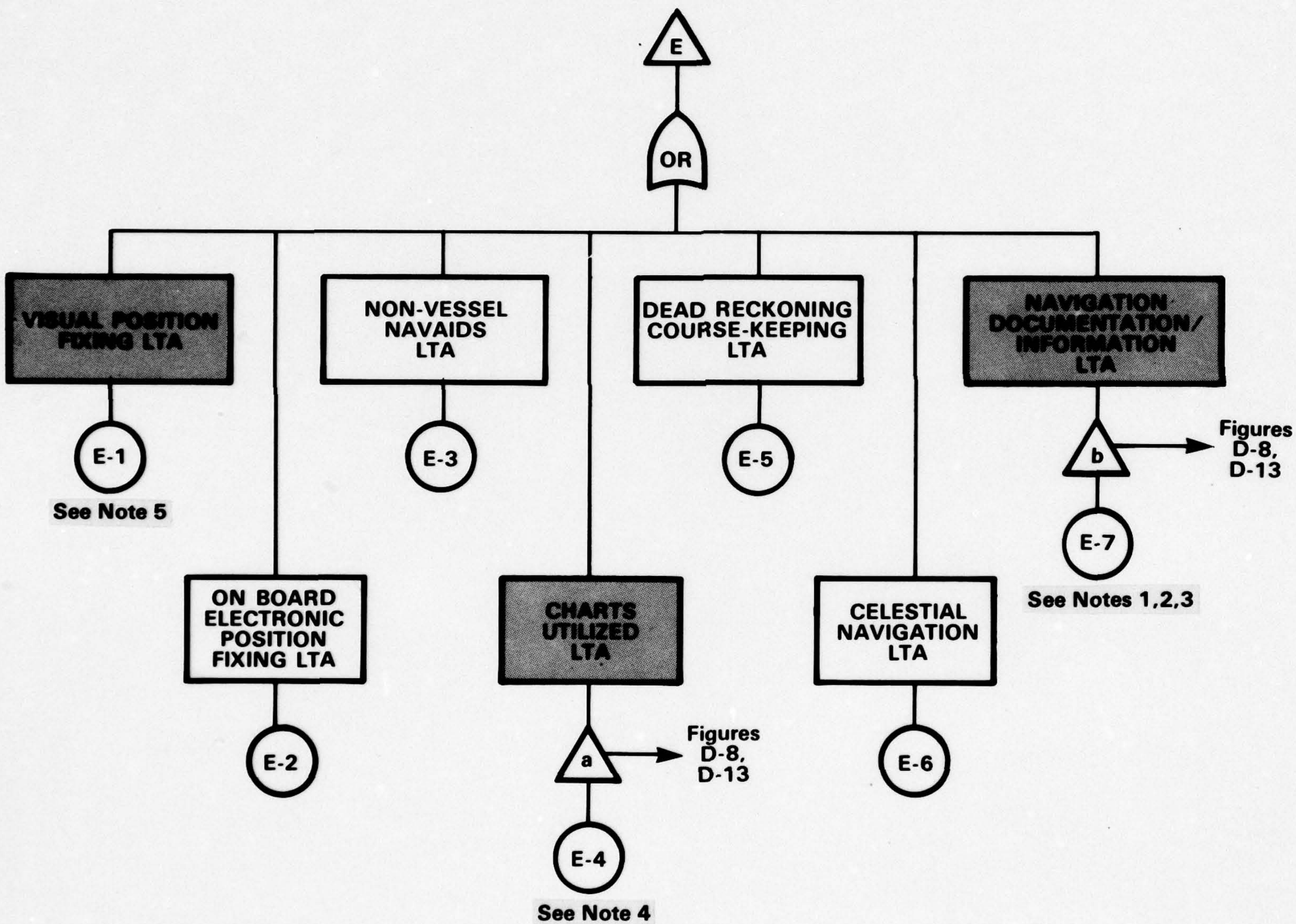


FIGURE D-12. DEPTH SURVEILLANCE LTA

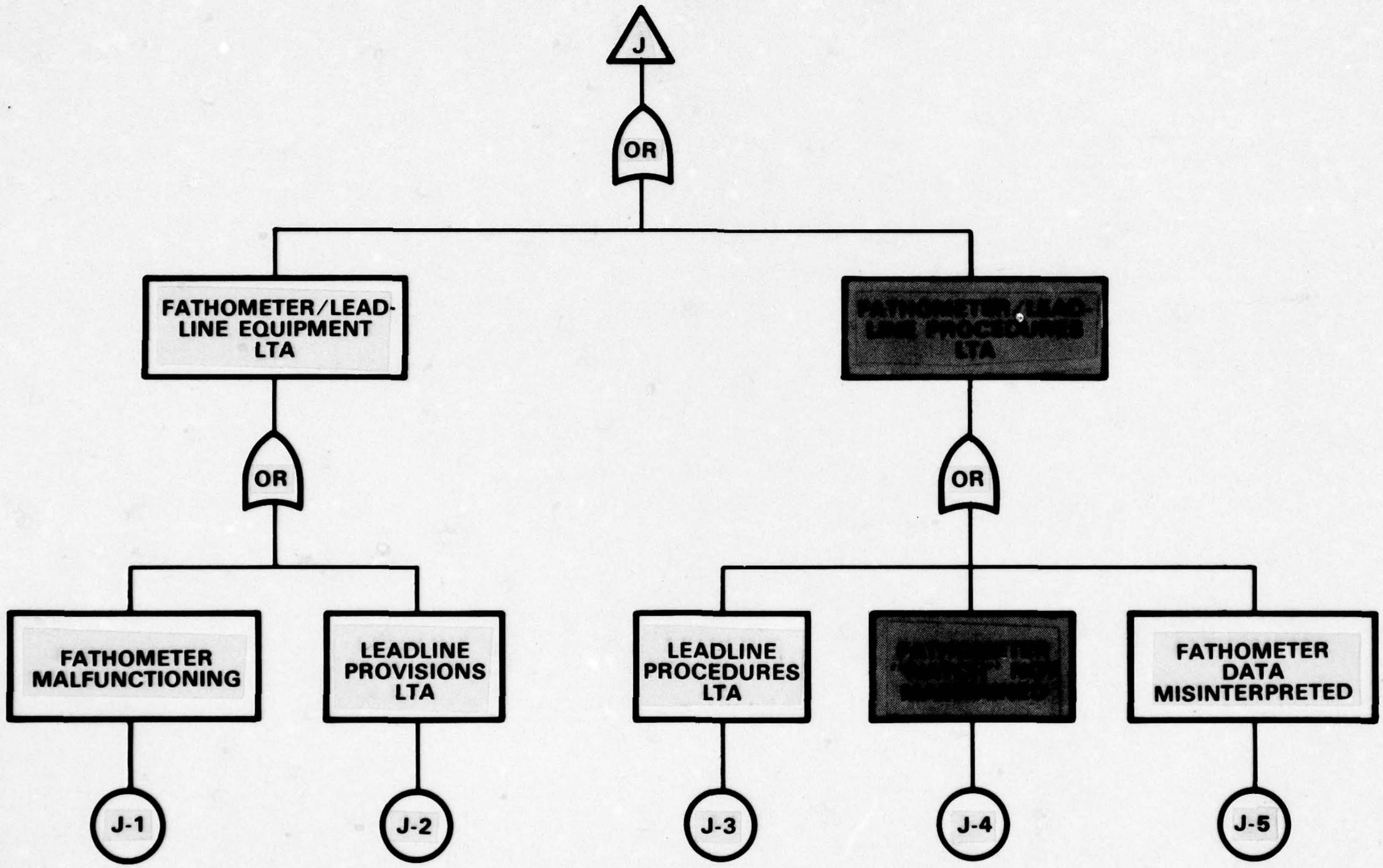


FIGURE D-4. EARLY ACTION LTA

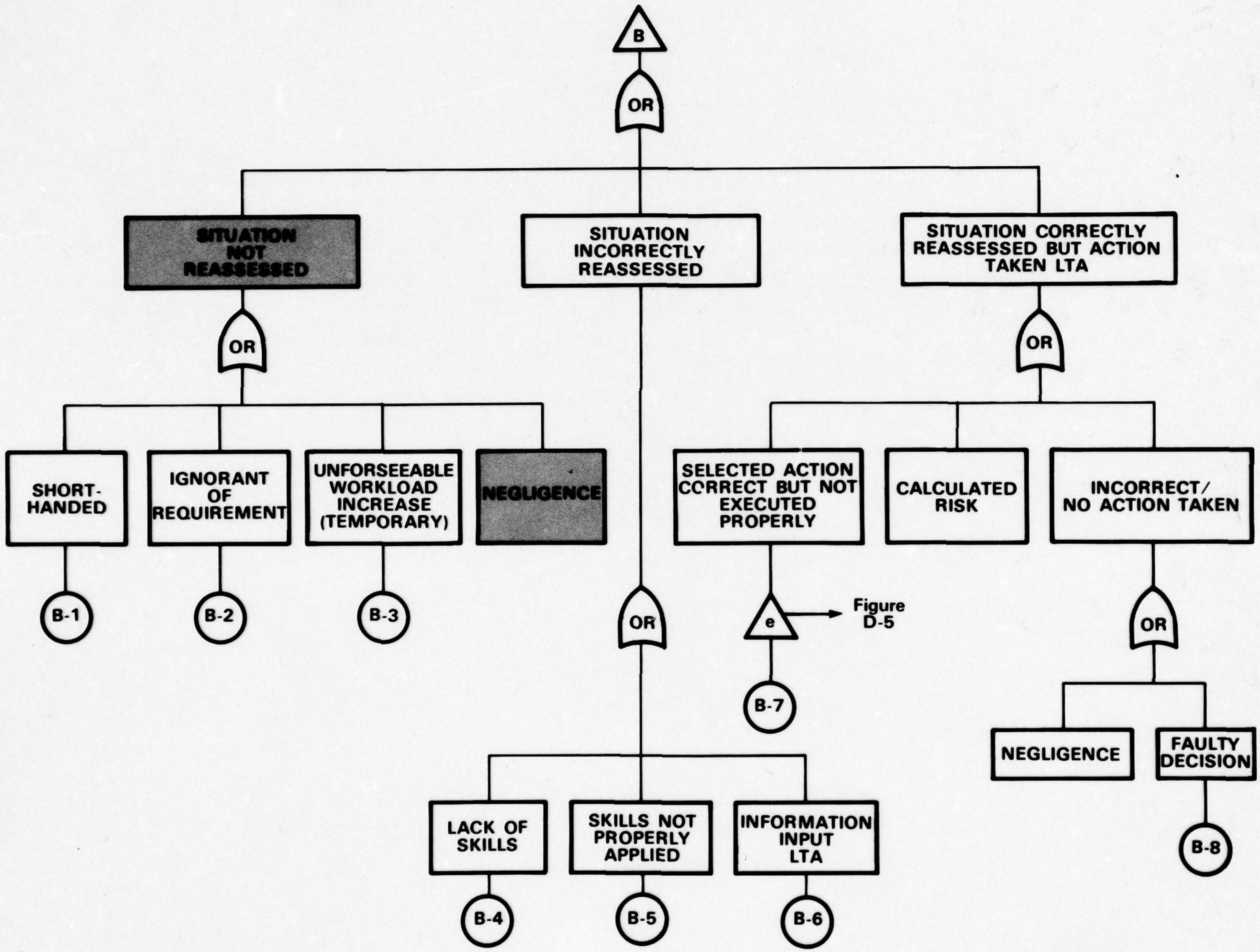
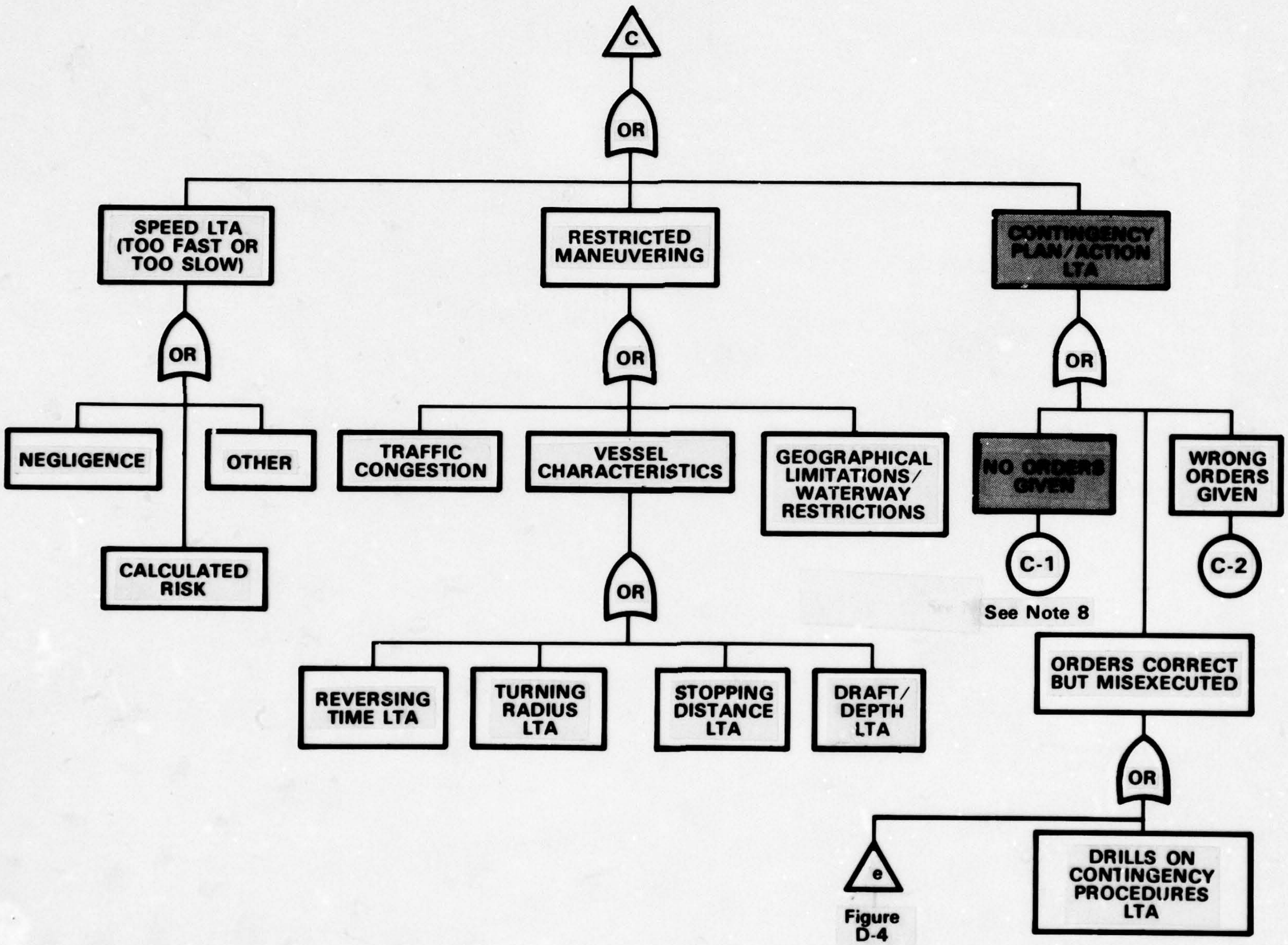


FIGURE D-5. AVOIDANCE ACTION LTA



Case 2, Grounding:	SS OCEAN EAGLE (LI) Grounding and breaking up with no loss of life, San Juan Harbor, 3 March 1968.
Weather:	Good visibility, 15 foot swells.
Background:	The pilot had tried to board the vessel, but couldn't due to the sea state. He was later able to get aboard after the vessel was already in trouble.

Notes*

1 The master did not use the Bar Channel Range (all buoys were on-station), thus conning the vessel into shoal water.

2 Essentially the same note as 1; if correct charting procedures had been applied, the impending danger would have been recognized.

3 The fathometer was not monitored and lead line soundings were not taken.

4 The criticality of the situation was not immediately appreciated, hence was not reassessed.

5 The master ordered the starboard anchor let go and the engine full astern. This resulted in the vessel swinging to starboard. The pilot got aboard at this point, and ordered left rudder and slow ahead to swing the vessel back to a safer position, but too late.

6 Swells lifting and dropping the vessel caused it to strike bottom three times and break in half.

* Refer to circled numbers on tree diagram that follow for case 2.

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE

SS OCEAN EAGLE GROUNDING

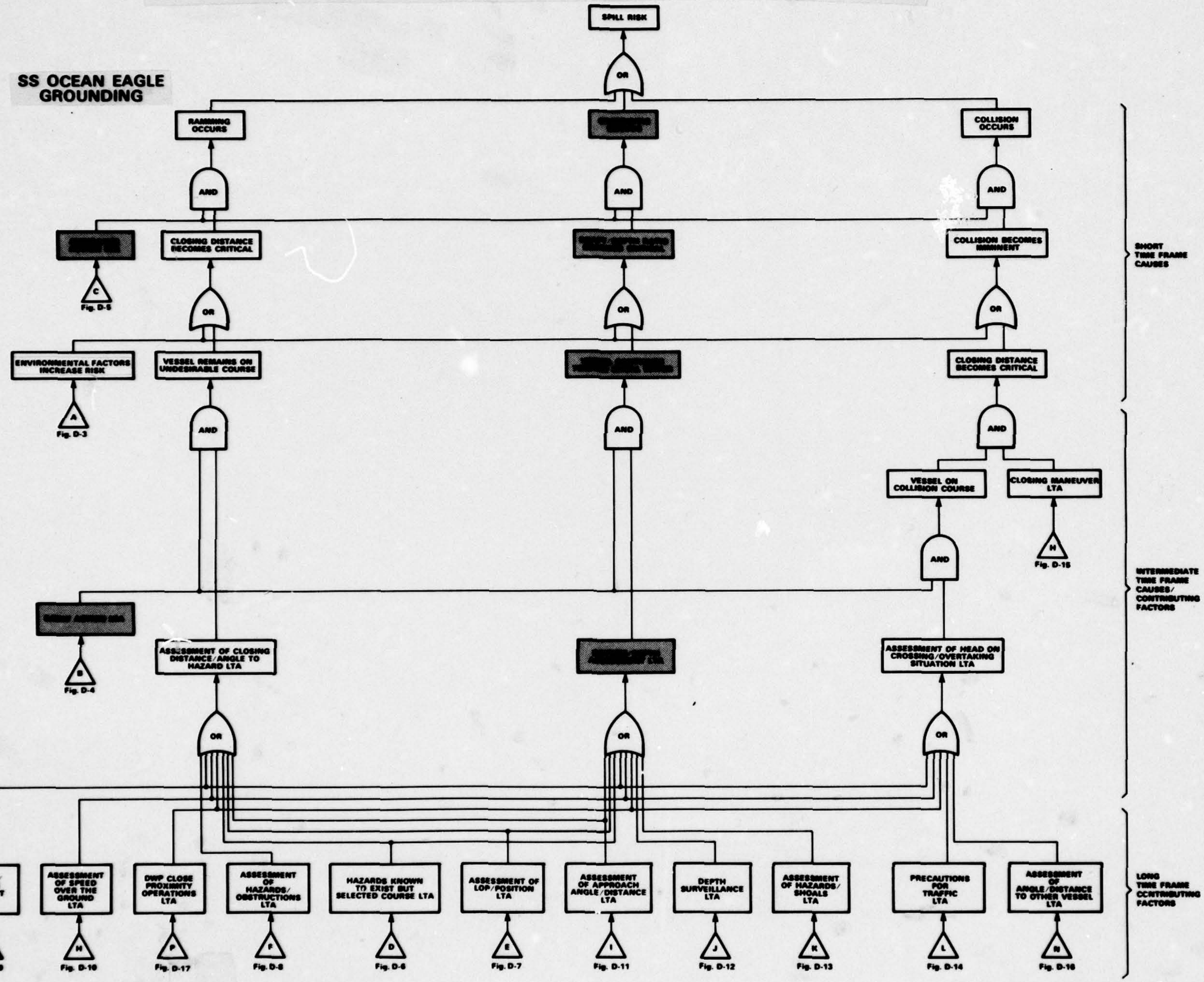
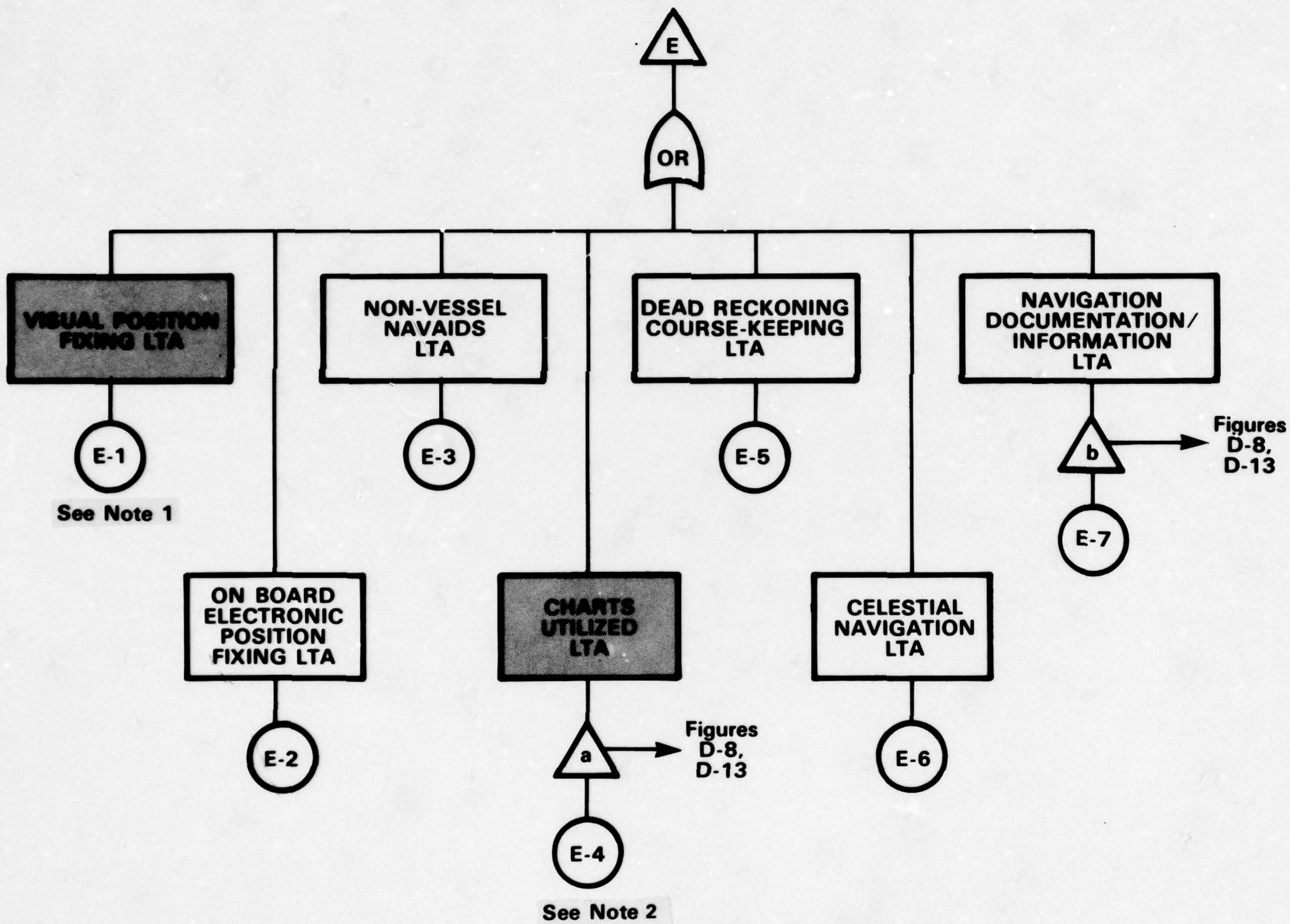


FIGURE D-7. ASSESSMENT OF LOP/POSITION LTA



332

FIGURE D-12. DEPTH SURVEILLANCE LTA

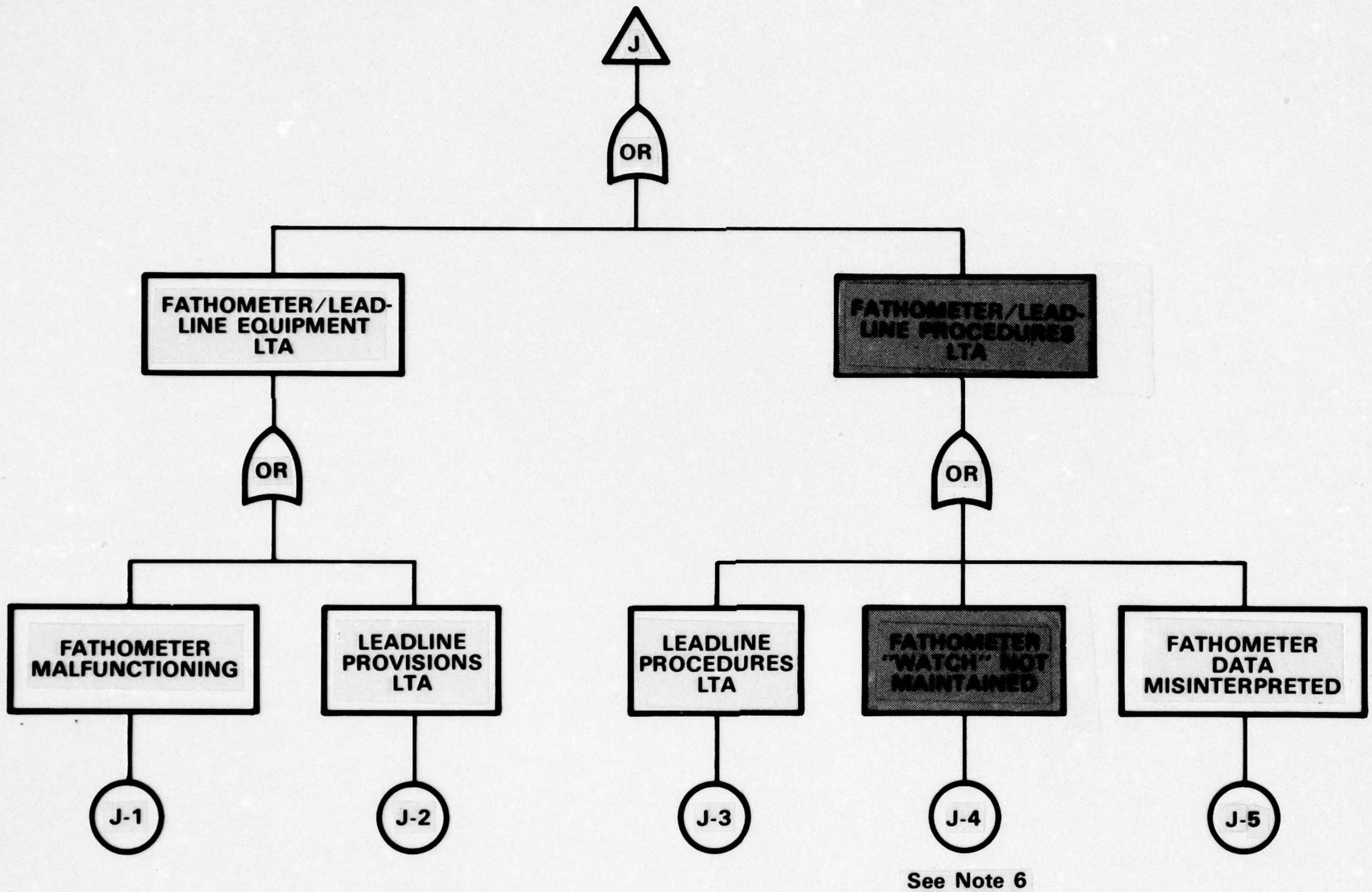


FIGURE D-4. EARLY ACTION LTA

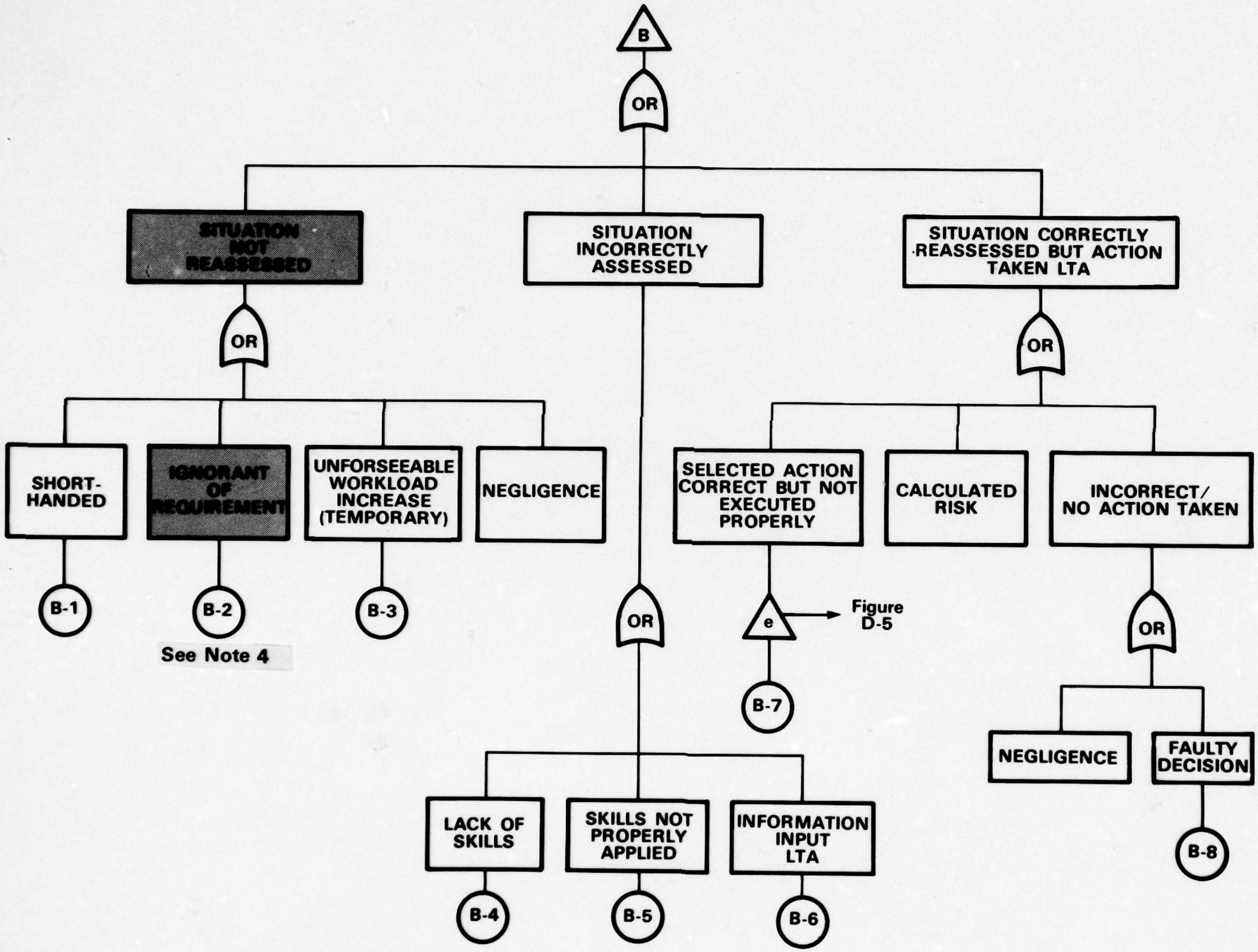
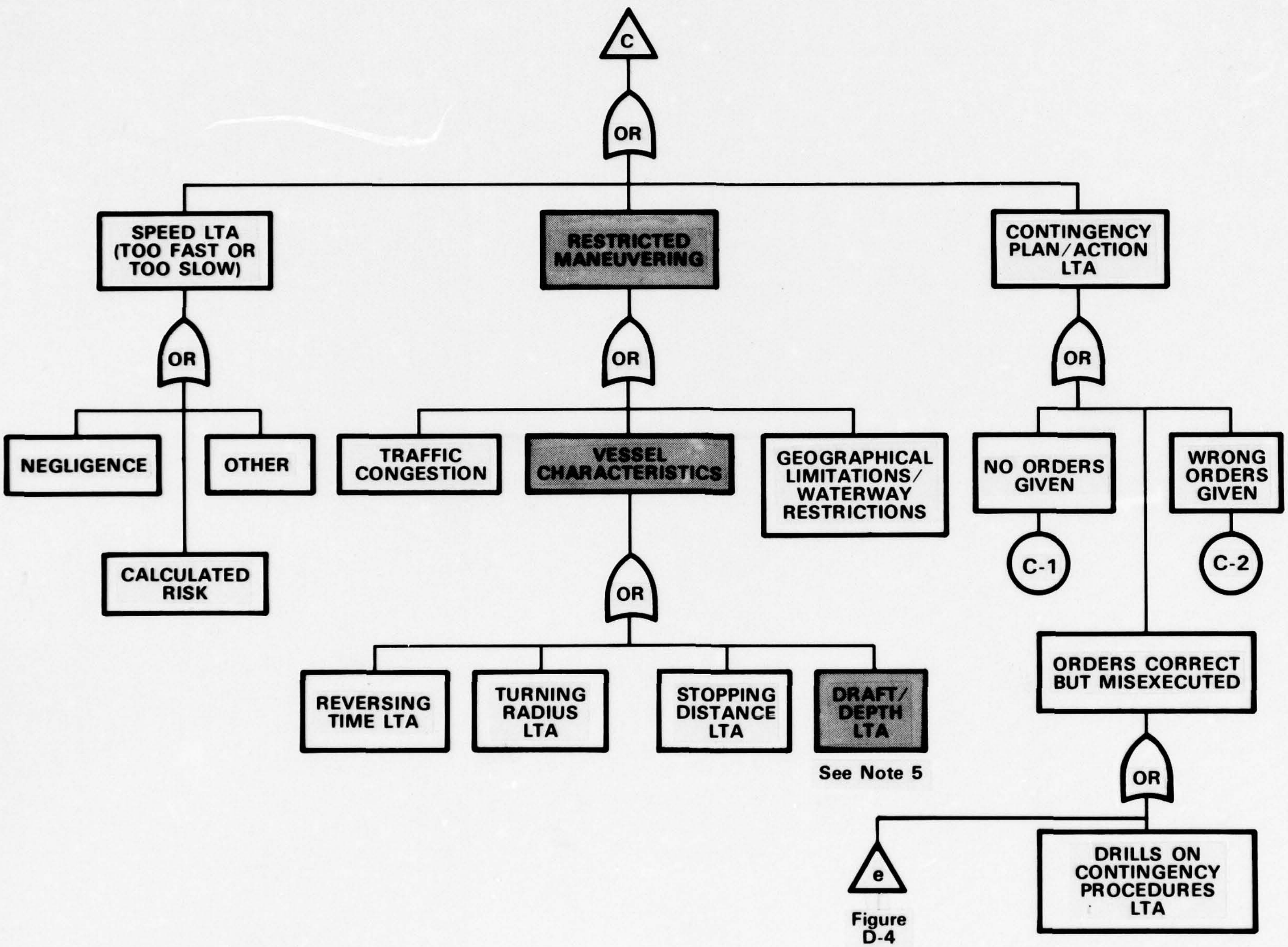


FIGURE D-5. AVOIDANCE ACTION LTA



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Case 3, Ramming: SS AFRICAN NEPTUNE: Collision with the Sidney Lanier Bridge at Brunswick, Georgia on 7 November 1972 with loss of life.

Background: A bend in the channel may require a vessel to be turning as it passes under the bridge opening.

Notes*

1 The helmsman failed to apply proper rudder in response to a helm order from the pilot.

2 The helmsman again failed to apply proper rudder to correct the above error. The heavy work on the bridge officers delayed detection of these efforts.

3 Attempts were made to stop the ship but to no avail due to its reversing/turning/stopping requirements. (The engines were ordered full astern, and the rudder hard-left, and the anchor was dropped.)

4 The vessel rammed the bridge, and 3 sections of the bridge collapsed and fell into the channel.

* Refer to circled numbers on tree diagrams that follow for case 3.

336

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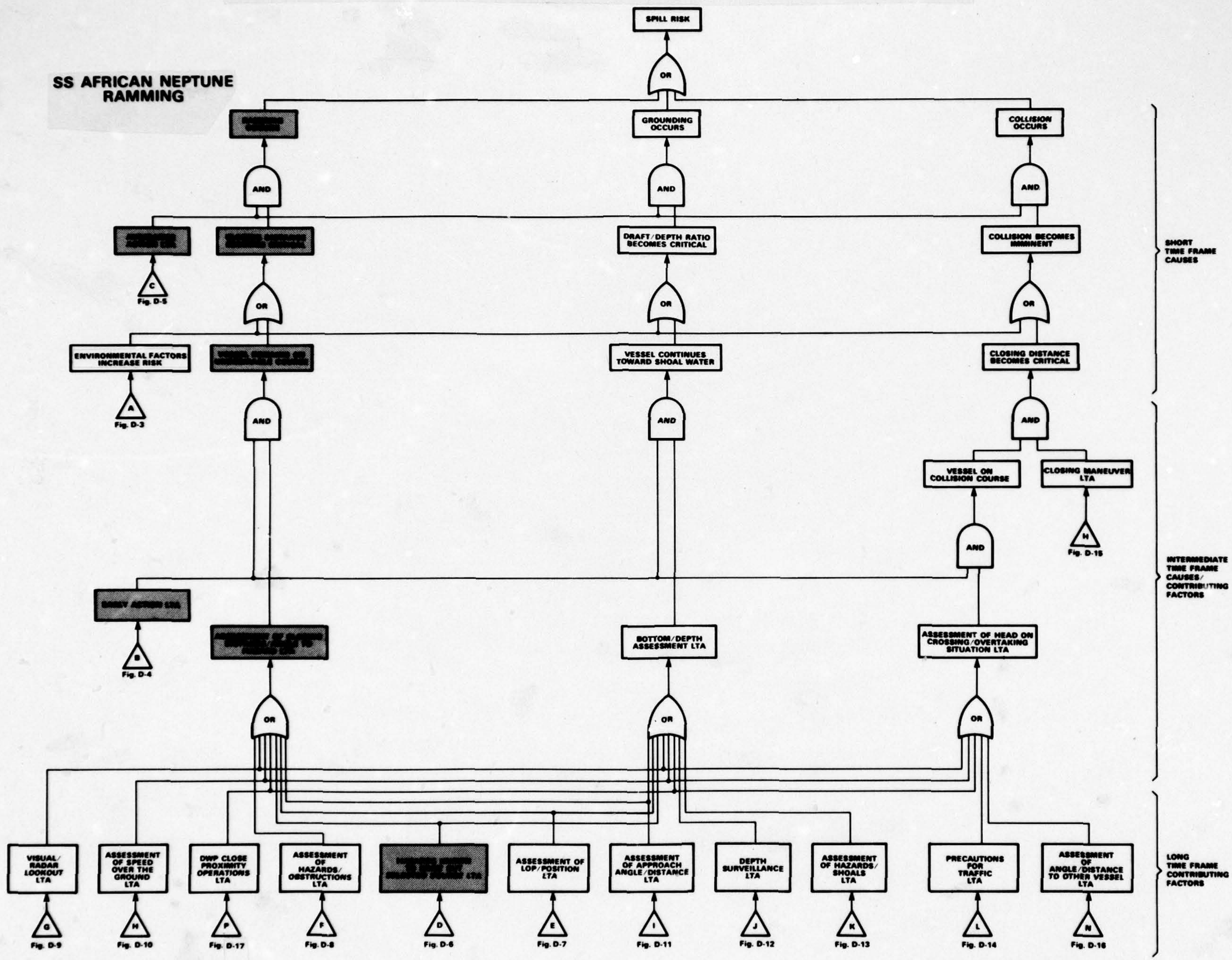
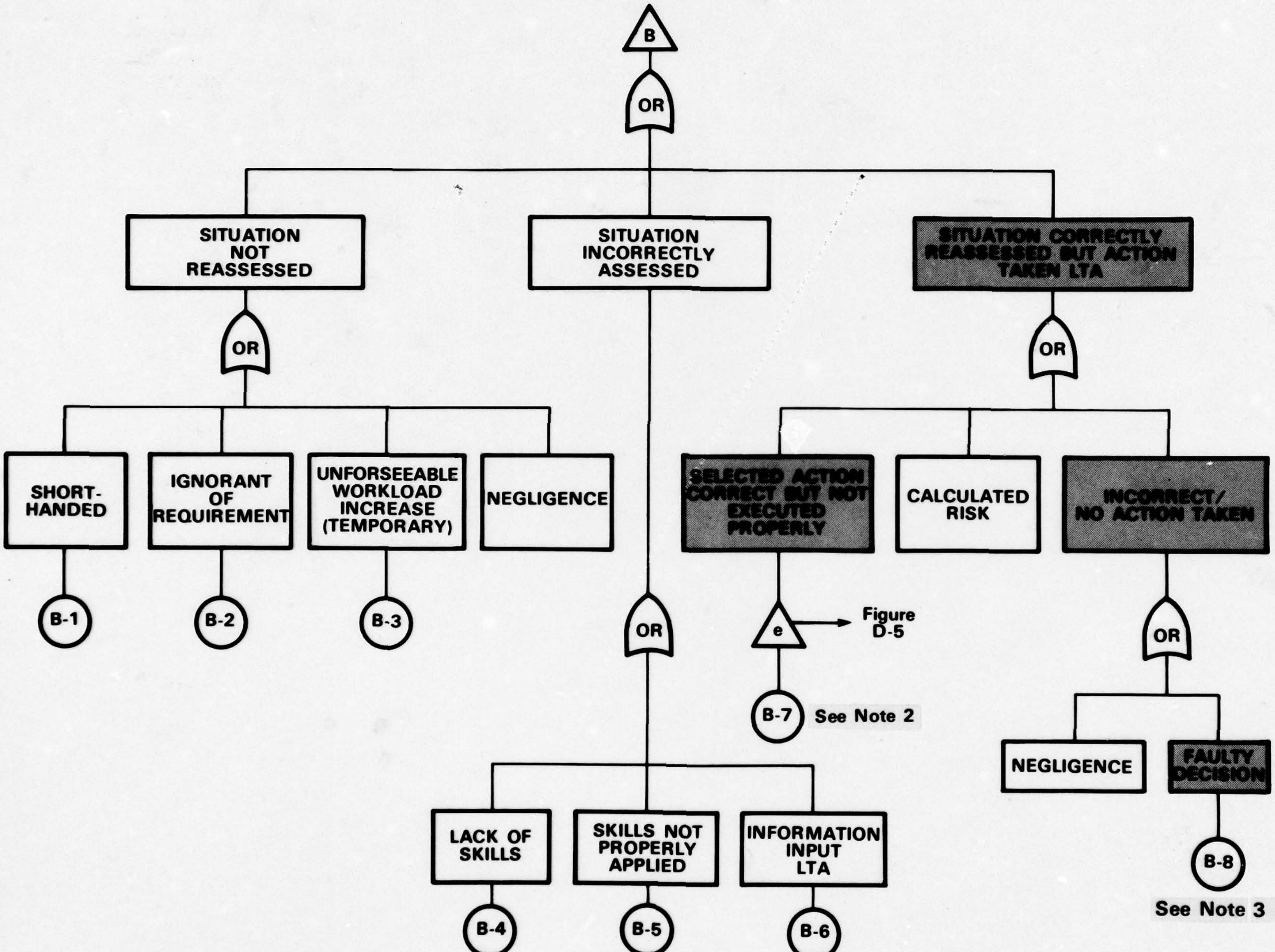
FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE



337

FIGURE D-4. EARLY ACTION LTA



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135

FIGURE D-6. HAZARD KNOWN TO EXIST BUT SELECTED COURSE LTA

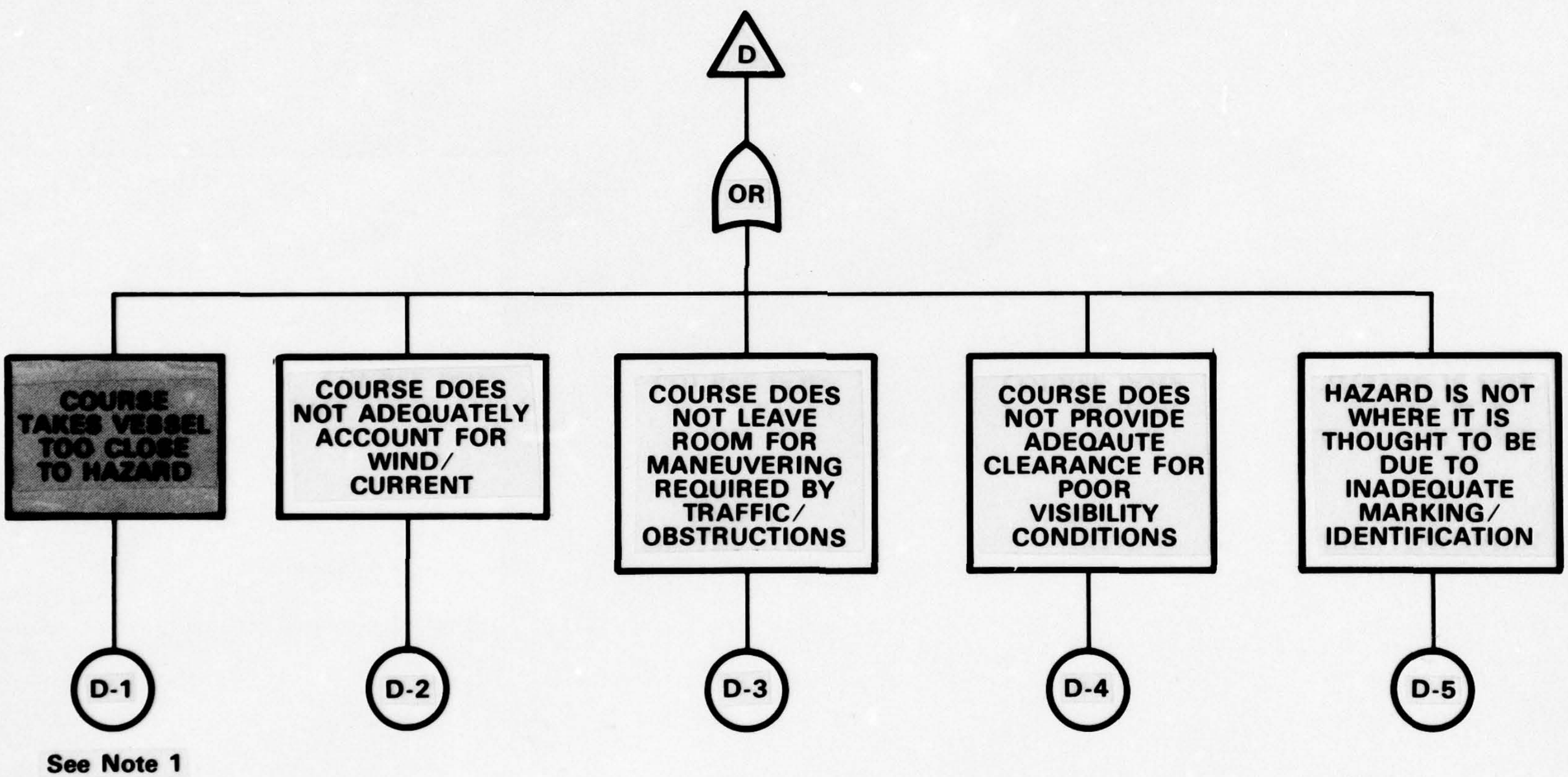
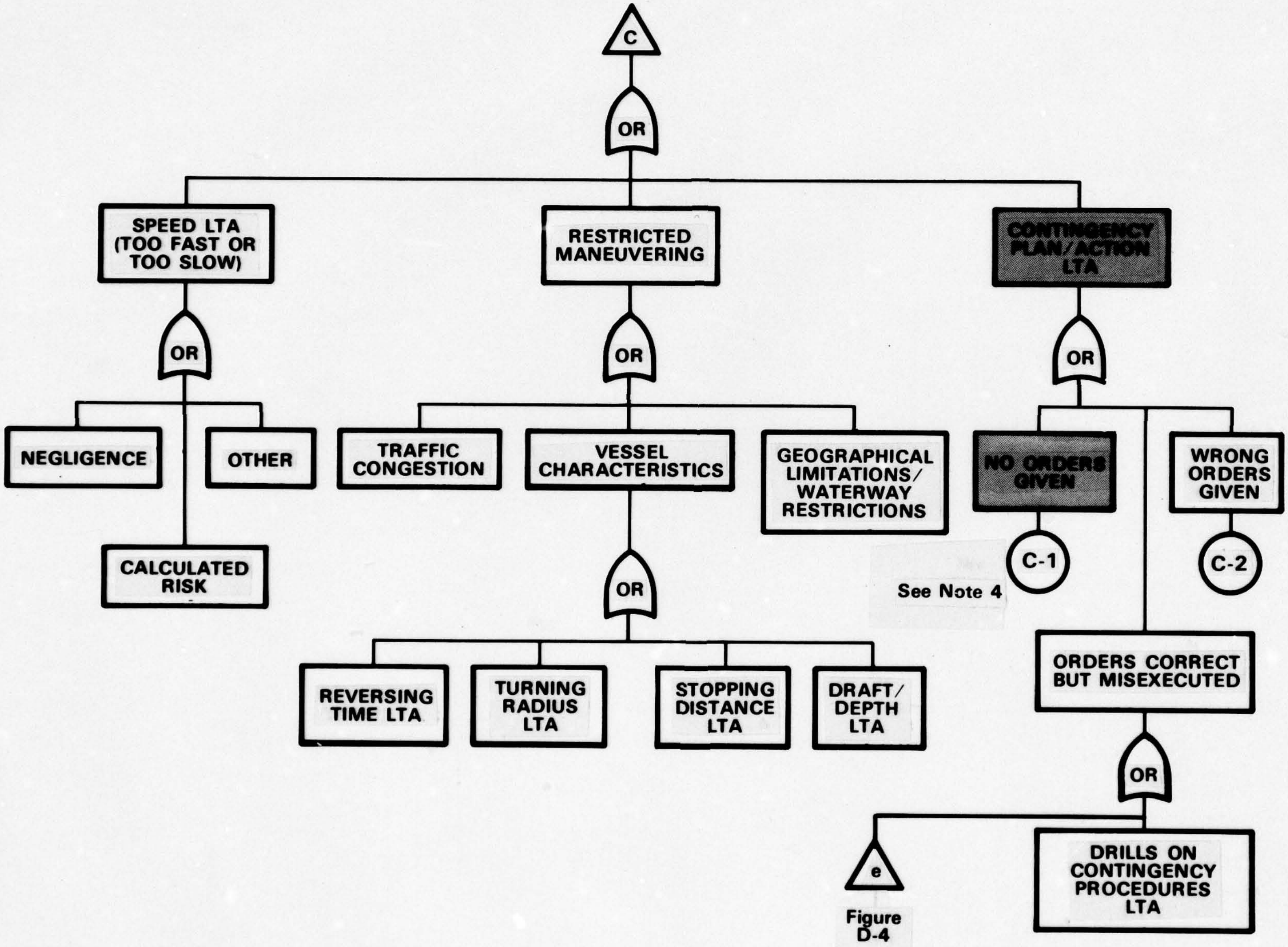


FIGURE D-5. AVOIDANCE ACTION LTA



Case 4, Ramming: SS EDGAR M. QUEENY - S/T CORINTHOS (LI): Collision at Marcus Hook, Pennsylvania, on 31 January 1975 with loss of life.

Background: Good visibility. At the time of the accident the QUEENY was executing a turn; the CORINTHOS was moored.

Notes*

1 The master became aware that the vessel would not make the commanded turn at the commanded speed. He pointed this out to the pilot, whose opinion was that there was plenty of room.

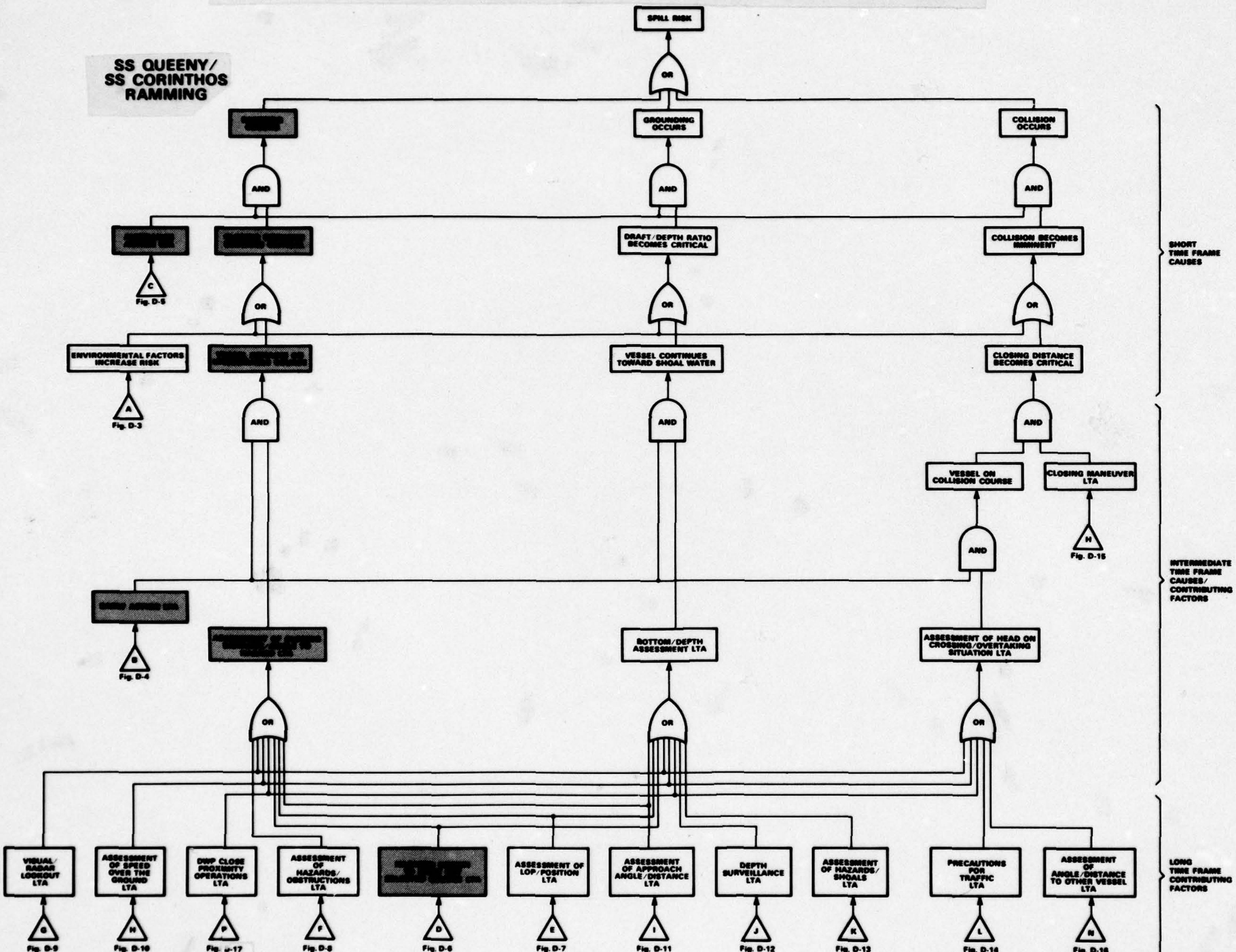
2 The master again warned the pilot that the turn could not be made, the the pilot was checking on downstream traffic via his radiotelephone.

3 The master ordered, the engines full astern, but too late. He also ordered the anchor let go, but the lookout at the bow had run aft when the accident became imminent.

4 The QUEENY rammed the moored CORINTHOS, and the CORINTHOS exploded and burst into flame.

* Refer to circled numbers on tree diagrams that follow for case 4.

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE



342

343

FIGURE D-5. AVOIDANCE ACTION LTA

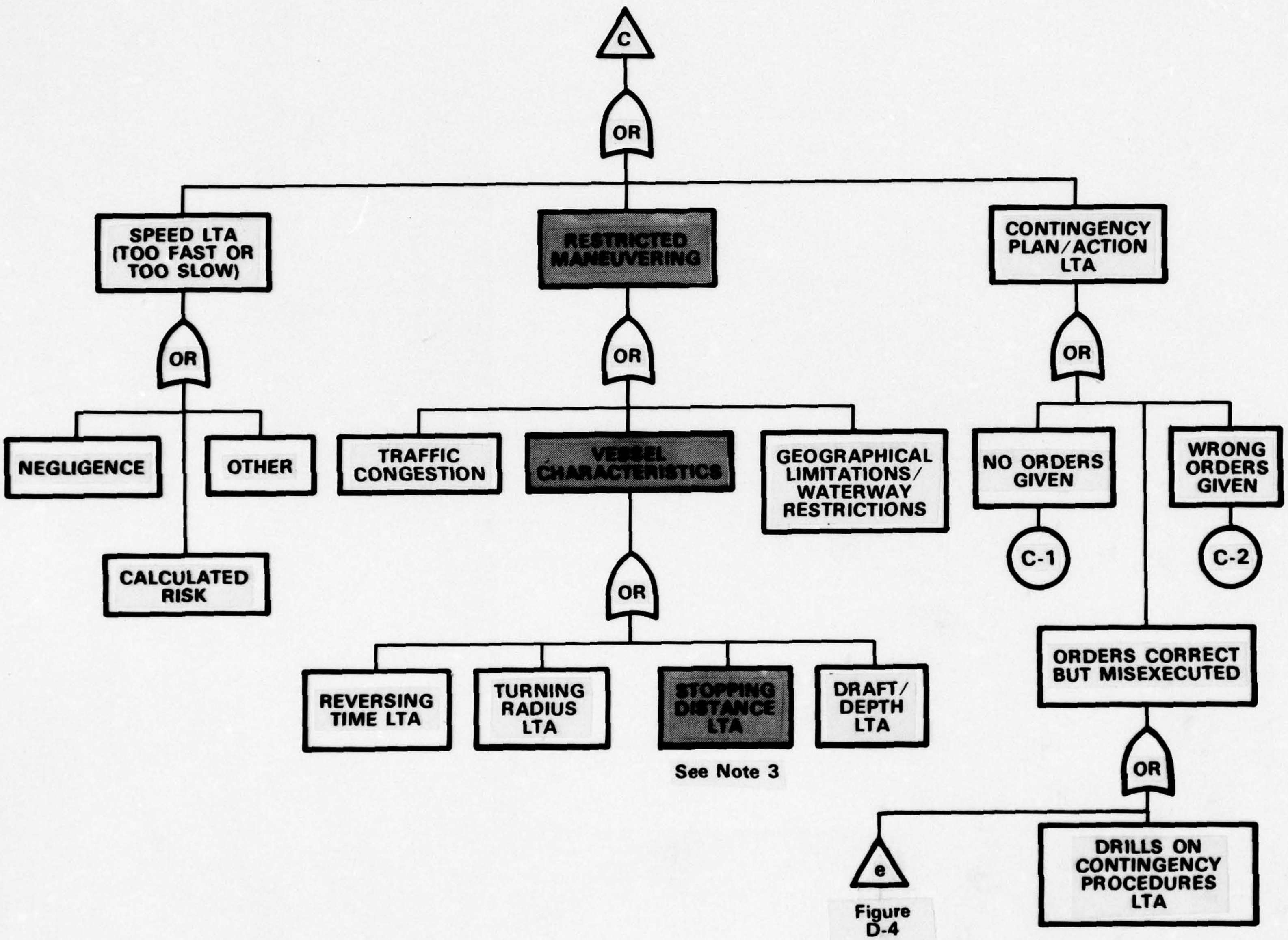


FIGURE D-4. EARLY ACTION LTA

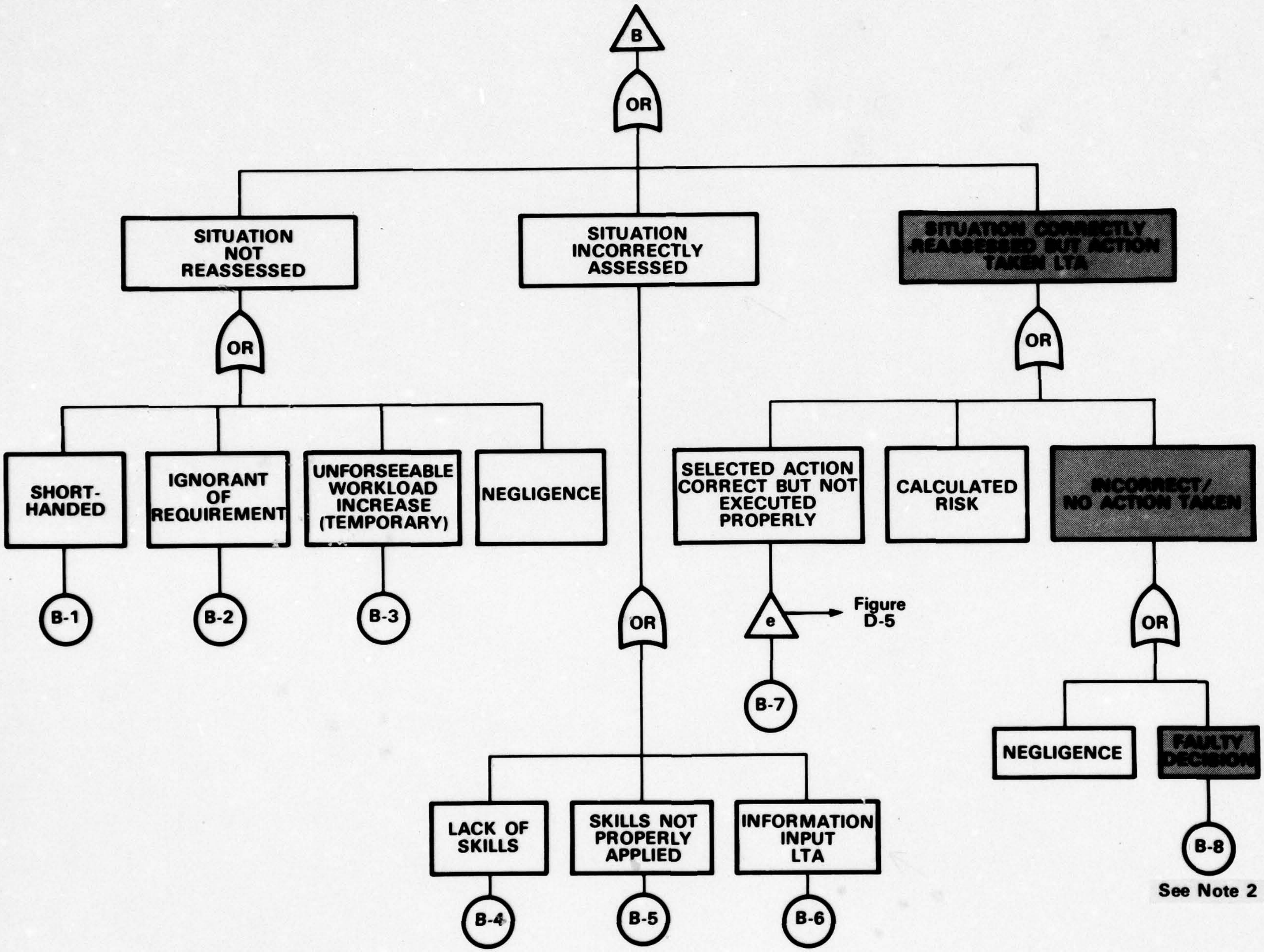
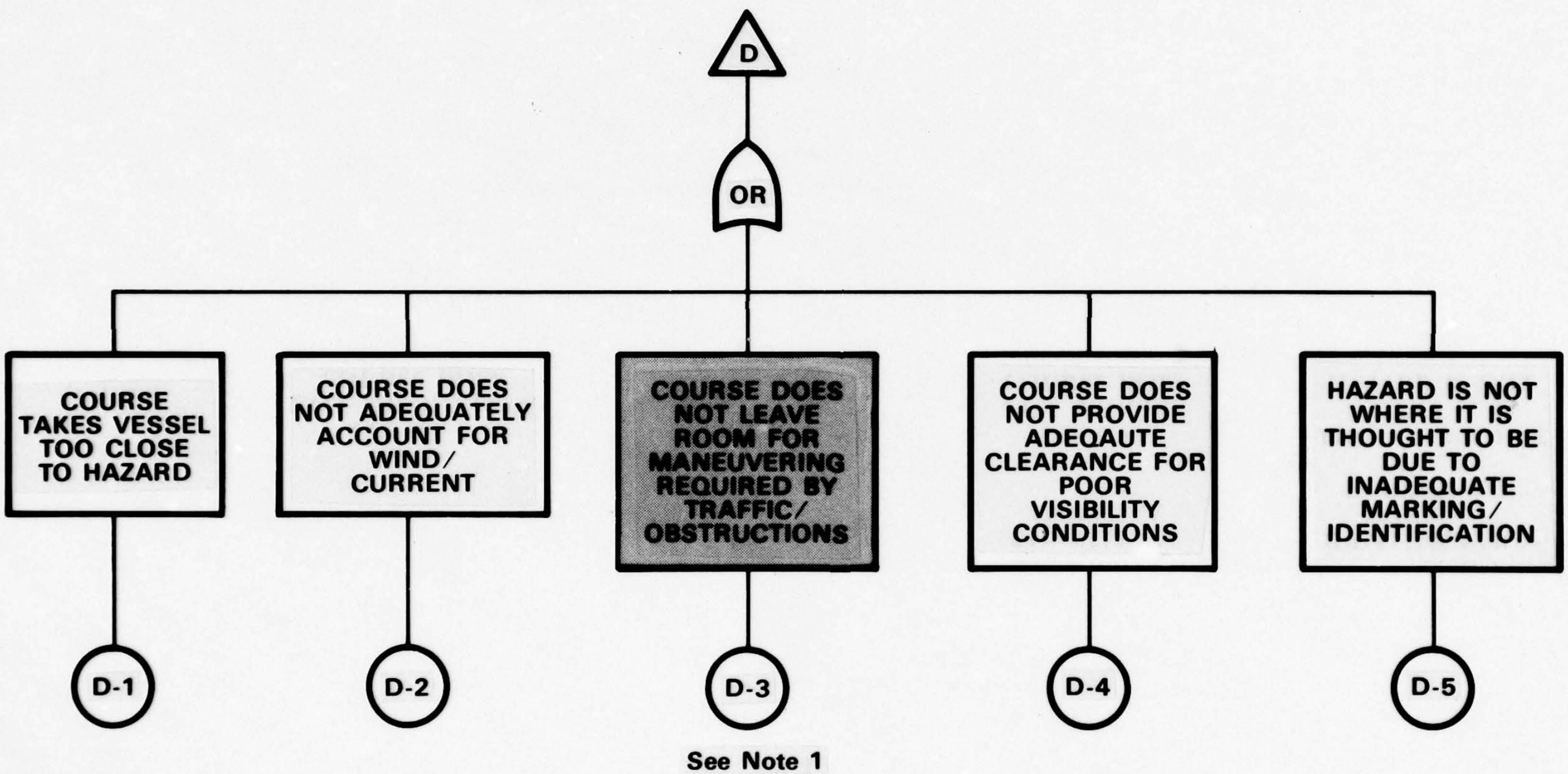


FIGURE D-6. HAZARD KNOWN TO EXIST BUT SELECTED COURSE LTA



Case 5, Collision: Collision involving the SS ARIZONA STANDARD and the SS OREGON STANDARD at the entrance to San Francisco Bay on January 18, 1971.

Background: Dense fog, 200 to 300 yard visibility. Both vessels were tracked by the Harbor Radar, which also advised both vessels of the other's passage and intended course.

Notes*

1 The ARIZONA bridge officer made some plots of the OREGON's position on his radar screen, but neglected to plot the associated times. The OREGON bridge officer did not maintain a sufficient radar watch because he was busy with other duties.

2 The ARIZONA master thought he was 175 to 600 yards Southwest of the Golden Gate Bridge center span. Harbor Advisory Radar proved that he was actually 900 yards Southwest of the center span. The OREGON master thought he was approximately 450 yards due west of the center of the bridge span; Harbor Advisory Radar proved he was 150 yards southwest by west of the center of the bridge. These errors put the vessels on collision course.

3 Neither vessel heard the other's fog signals due to high noise level created by the diaphone and fog horns on the Golden Gate Bridge.

4 The ARIZONA made several attempts to contact the OREGON via radiotelephone, but to no avail.

5 Both vessels were travelling at immoderate speeds for the visibility conditions. They could have gone slower and still maintained steerage-way:

6 There is no indication that the ARIZONA appreciated the seriousness of the situation and took any action.

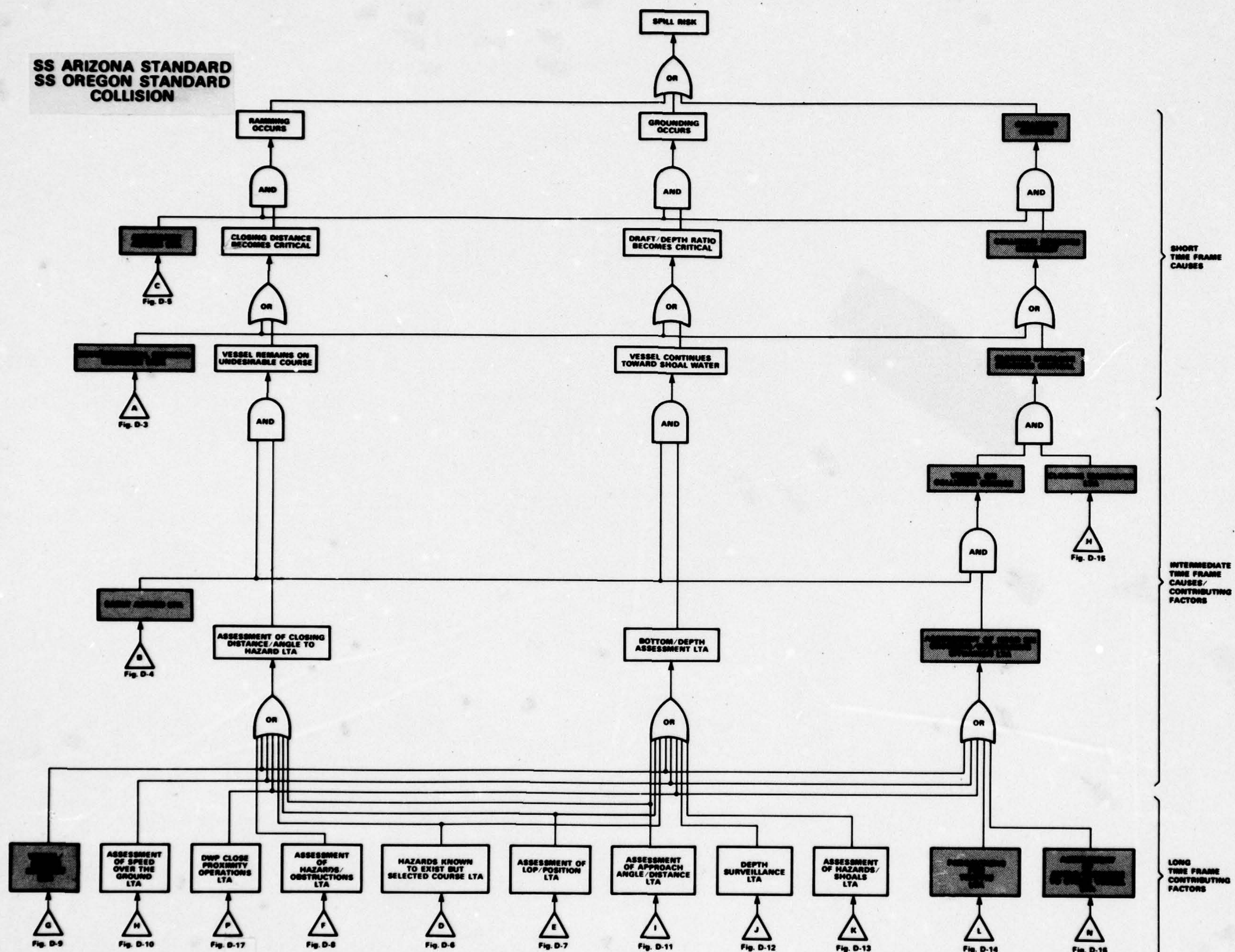
7 The OREGON master saw the ARIZONA on radar at 0.8 mile, and tried to contact it via radiotelephone. However, he selected the wrong radiotelephone channel.

8 There is no indication that a passing manuever was attempted.

9 The OREGON master visually saw the ARIZONA just prior to contact, and ordered engines full astern, but too late to avoid collision.

* Refer to circled numbers on tree diagrams that follow for case 5.

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE



347 348

FIGURE D-3. ENVIRONMENTAL FACTORS INCREASE RISK

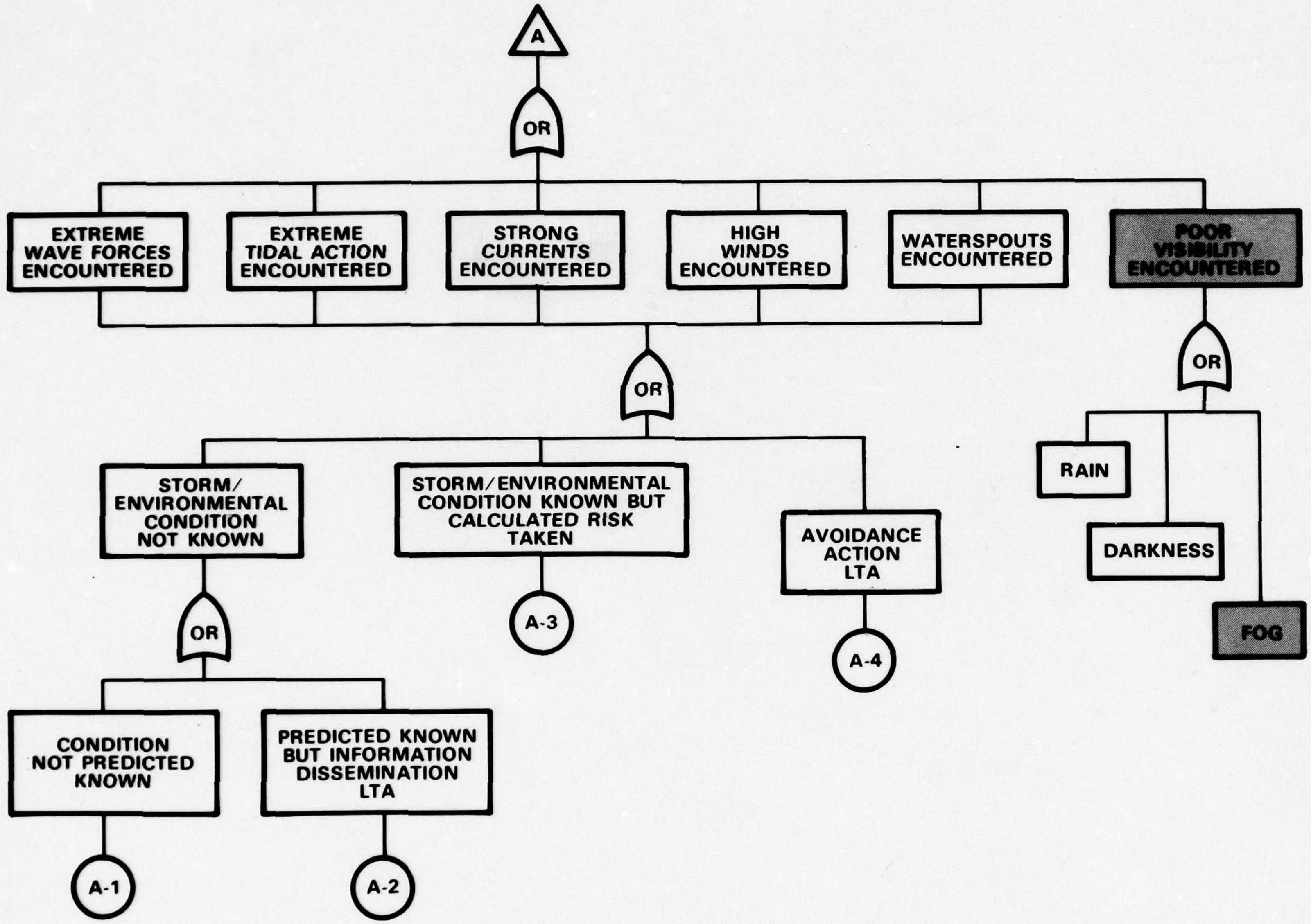


FIGURE D-5. AVOIDANCE ACTION LTA

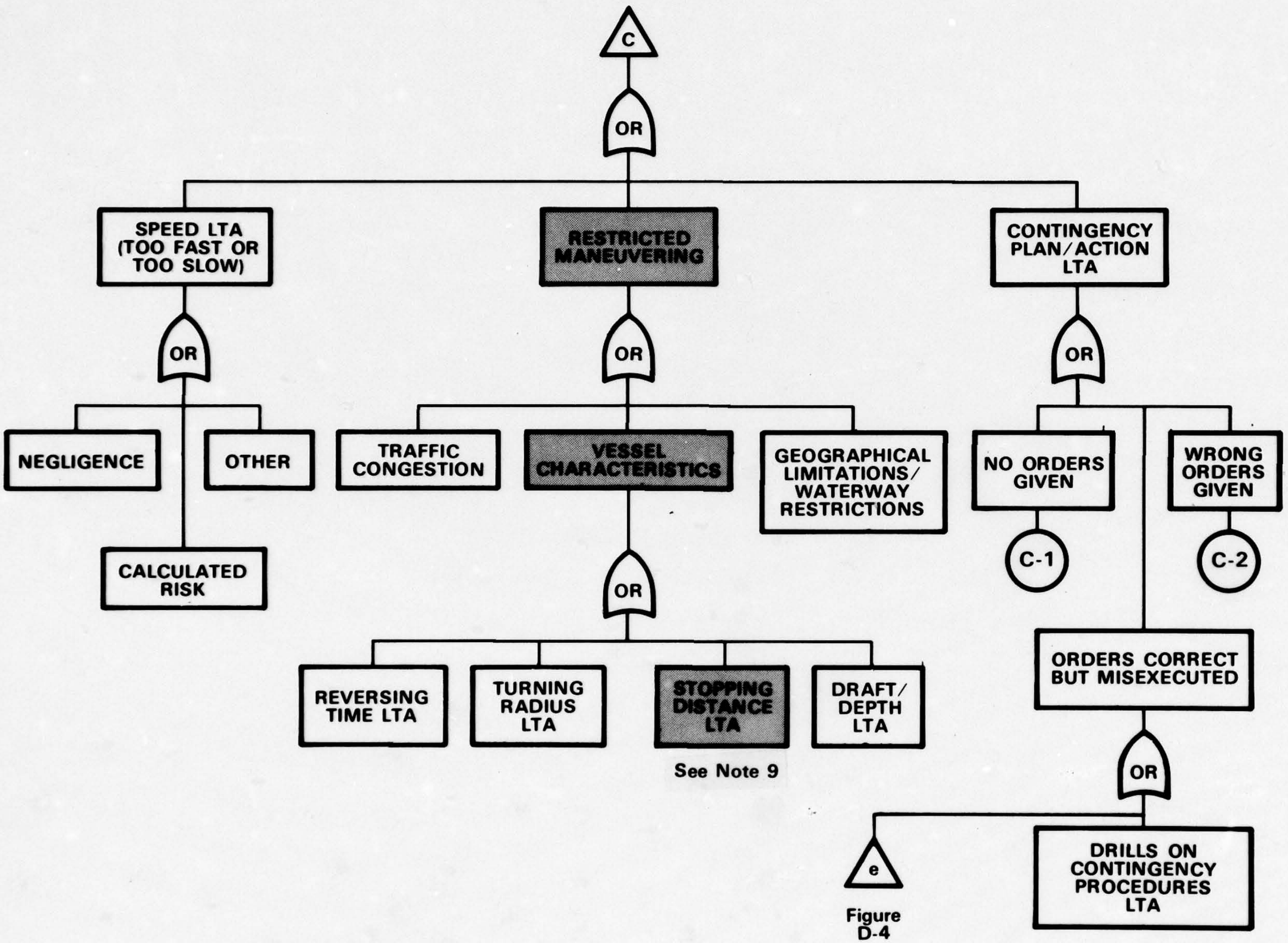


FIGURE D-16. CROSSING AND OVERTAKING MANEUVER LTA

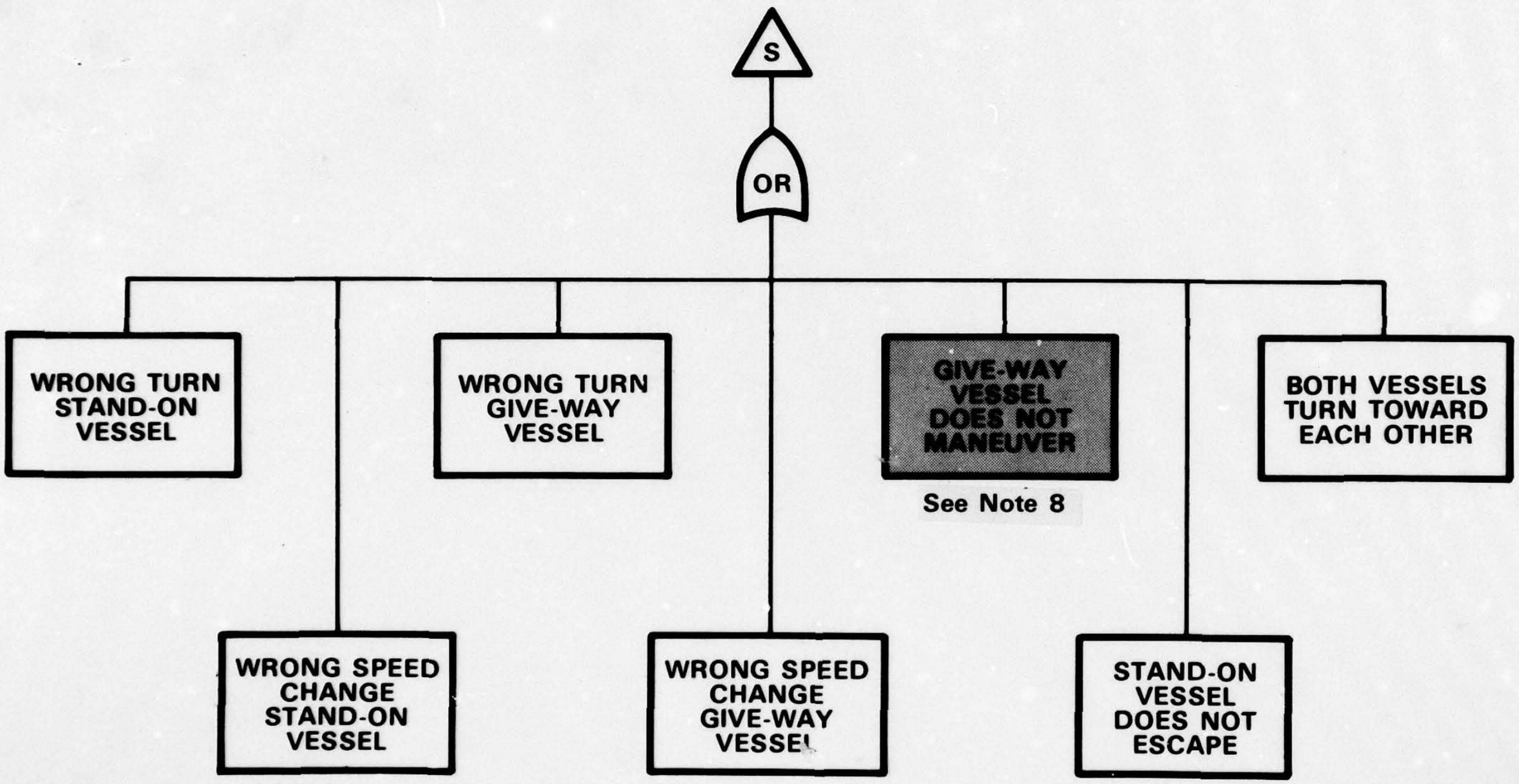
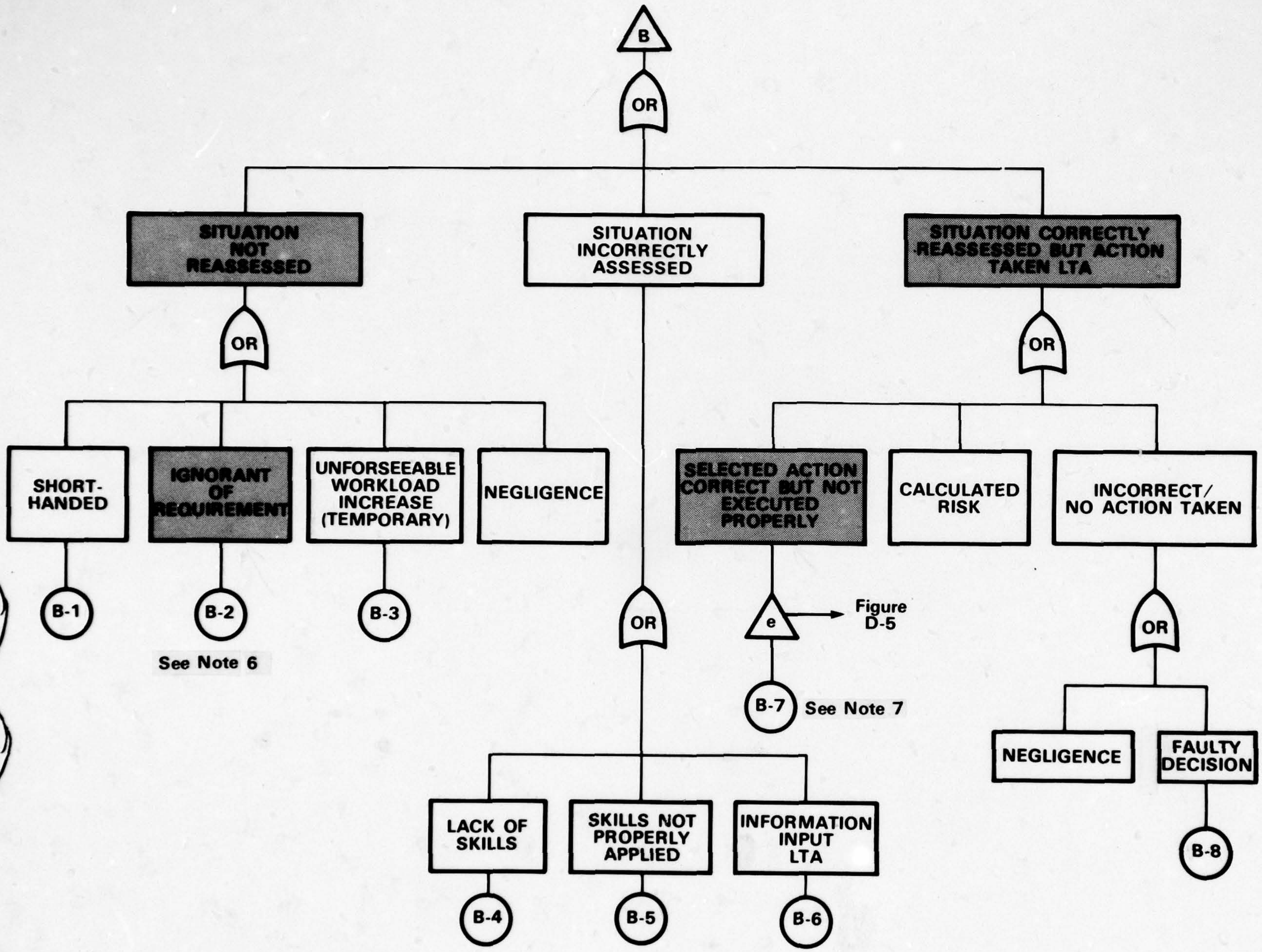


FIGURE D-4. EARLY ACTION LTA



351

FIGURE D-14. PRECAUTIONS FOR TRAFFIC LTA

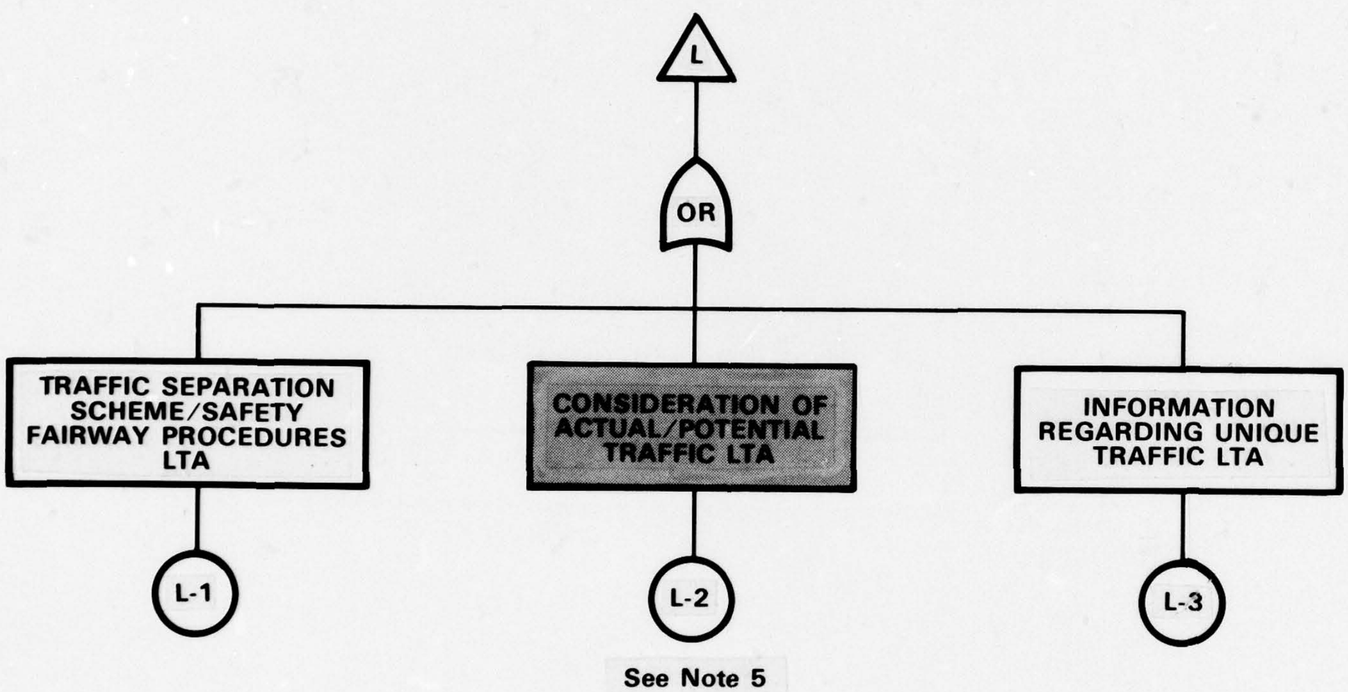
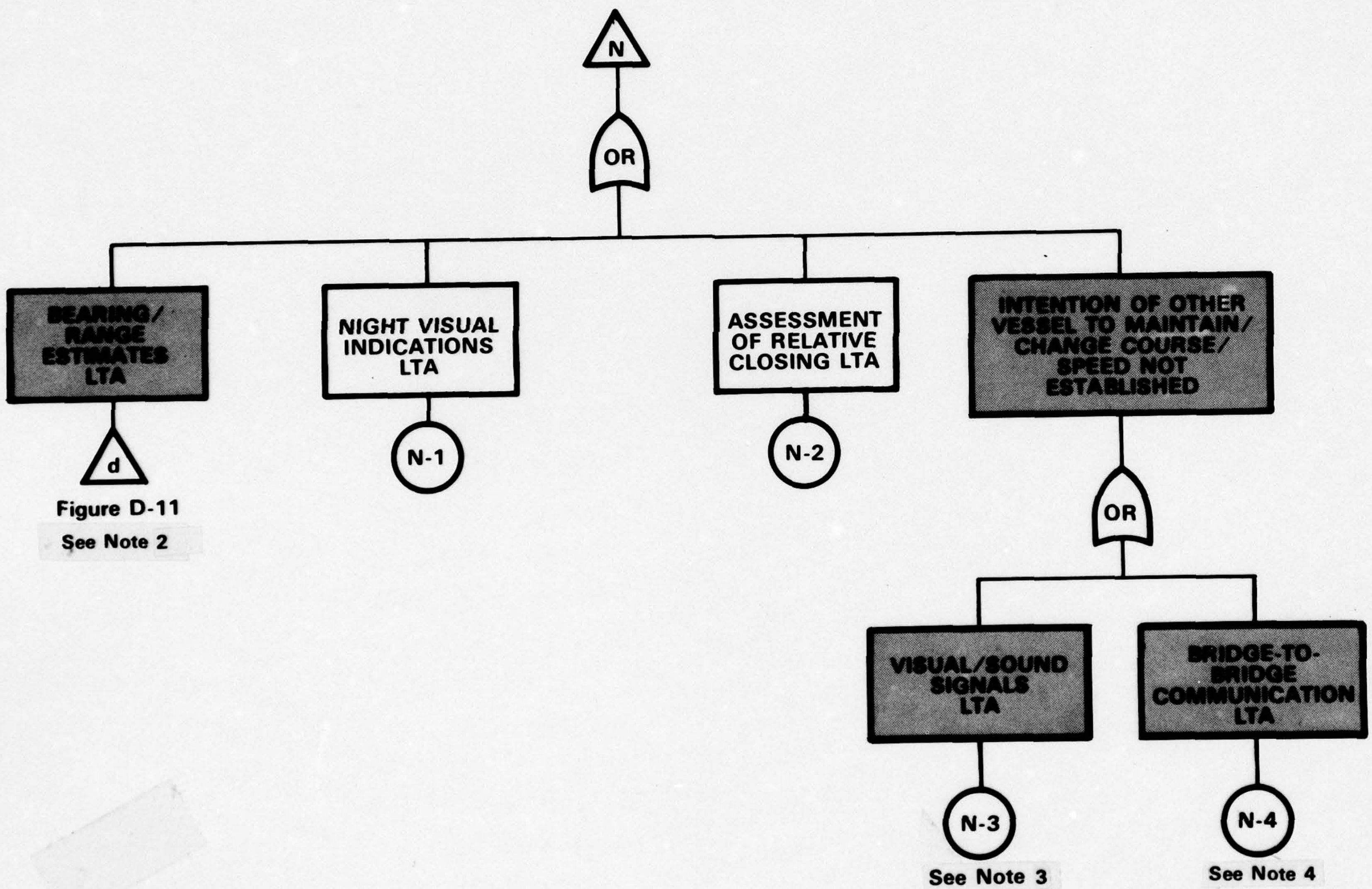


FIGURE D-17. ASSESSMENT OF ANGLE/DISTANCE TO OTHER VESSEL LTA



353

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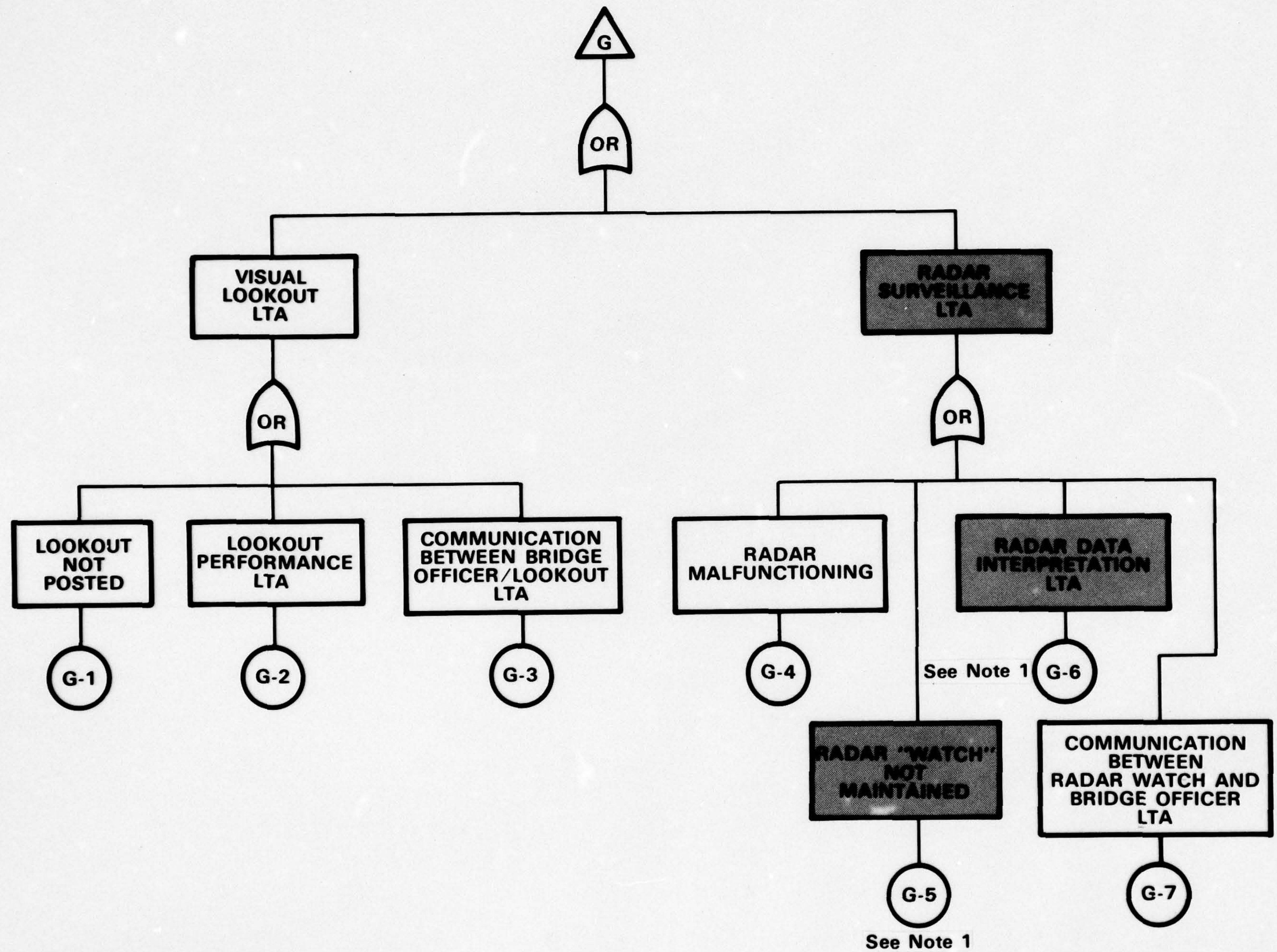
FIGURE D-9. VISUAL/RADAR LOOKOUT LTA



~~358~~ 354

Case 6, Collision: SS KEYTRADER and SS BAUNE (NO) collision in the Mississippi River on 18 January 1974 with loss of life

Background: There was low-lying fog (10 to 30 feet high) which restricted visibility, but superstructures would have been visible above the fog layer.

Notes*

1 Neither vessel monitored radar continuously.

2 BAUNE failed to maintain a lookout.

3 KEYTRADER's pilot saw BAUNE's masts, but due to the effects of the low-lying fog misinterpreted the angle, thus mistakenly thinking that BAUNE was coming out of the anchorage area rather than proceeding upstream.

4 No attempts were made to establish bridge-to-bridge communications at an early stage, due in part, to heavy radio traffic on channel 13, and in part to the pilot's reluctance to routinely broadcast his position.

5 KEYTRADER sounded a two-blast passing signal, which BAUNE did not hear due to the effects of sound propagation in the fog, and the wind direction.

6 KEYTRADER sounded the four-blast danger signal, then turned to port for an improper starboard to starboard passing.

7 Neither vessel reduced speed until approximately 1 minute before collision.

8 The KEYTRADER's master saw the BAUNE and ordered full astern. The BAUNE's bridge officer also ordered full astern, but both actions were too late to prevent collision.

* Refer to circled numbers in tree diagrams that follow for case 6.

FIGURE D-2. DWP TRANSIT OPERATIONS TOP LEVEL FAULT TREE

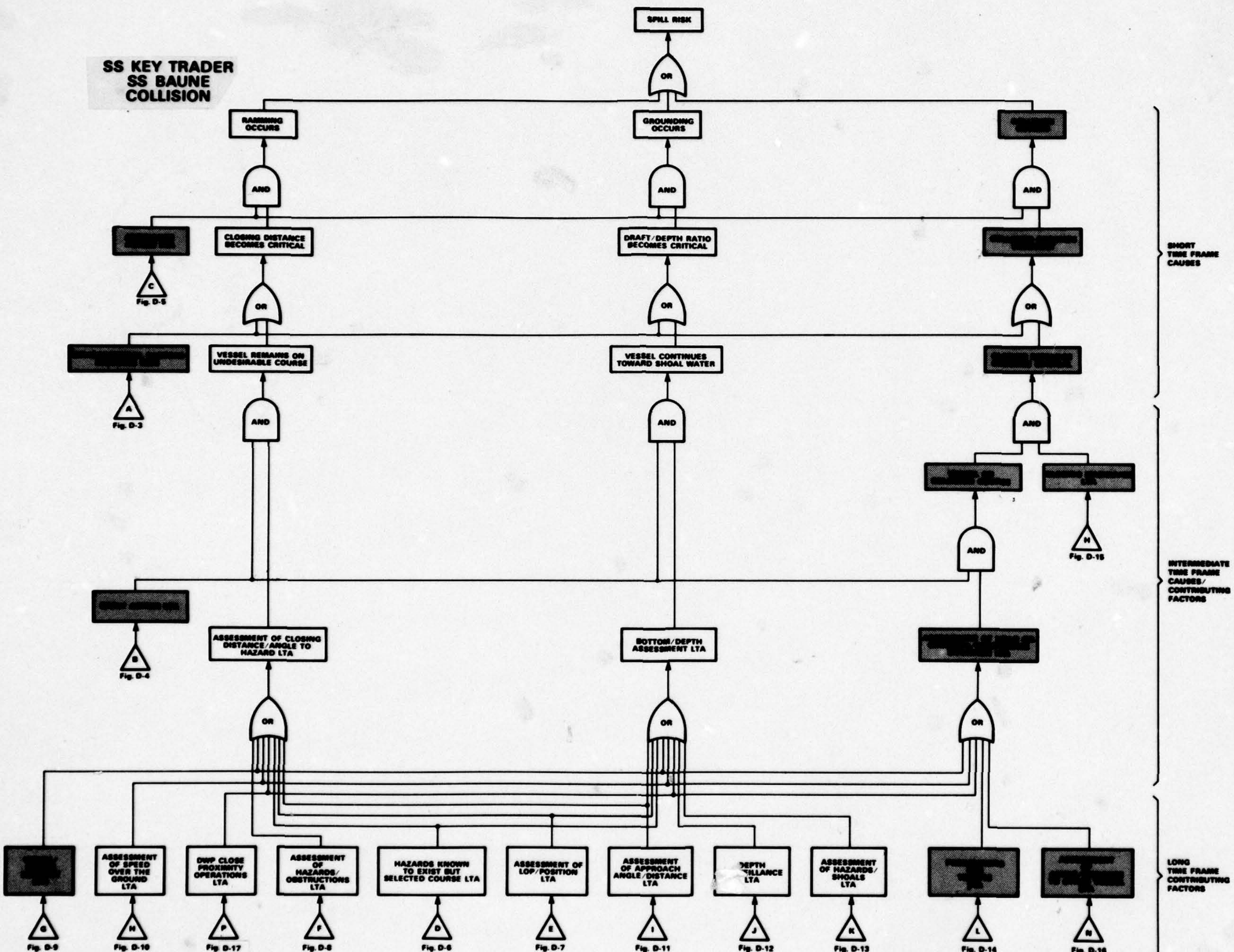
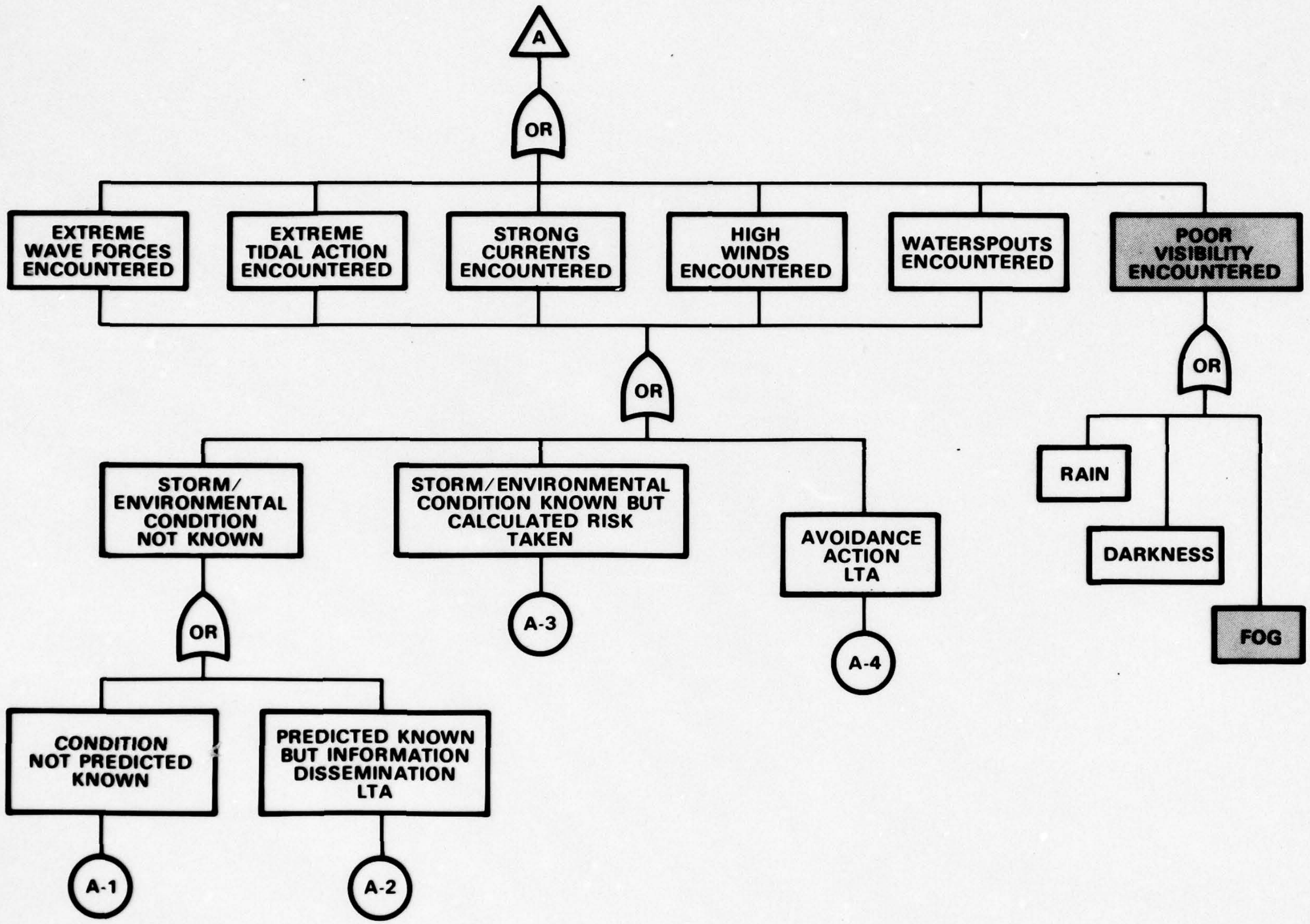


FIGURE D-3. ENVIRONMENTAL FACTORS INCREASE RISK



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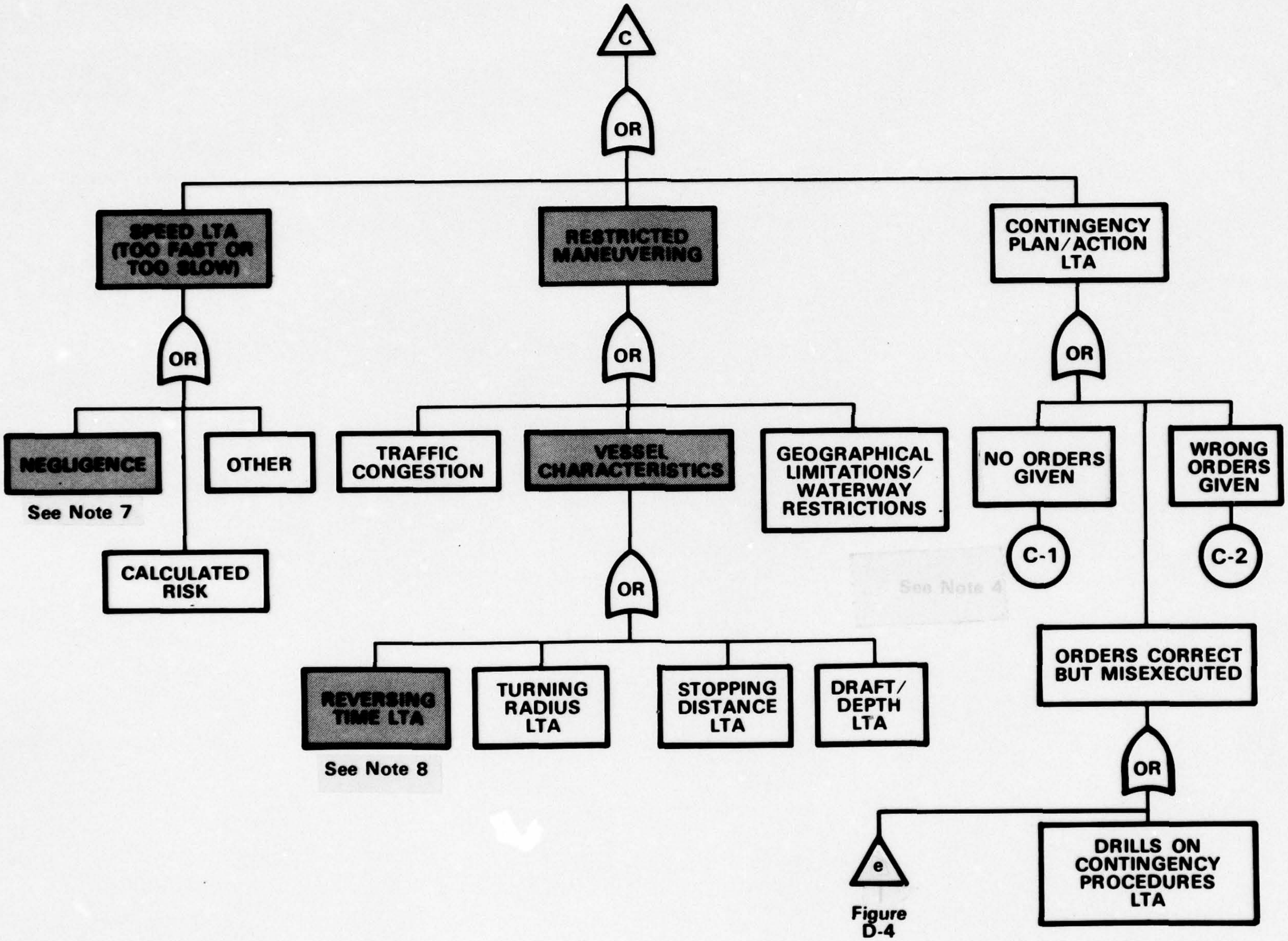
357

FIGURE D-5. AVOIDANCE ACTION LTA



358

FIGURE D-16. CROSSING AND OVERTAKING MANEUVER LTA

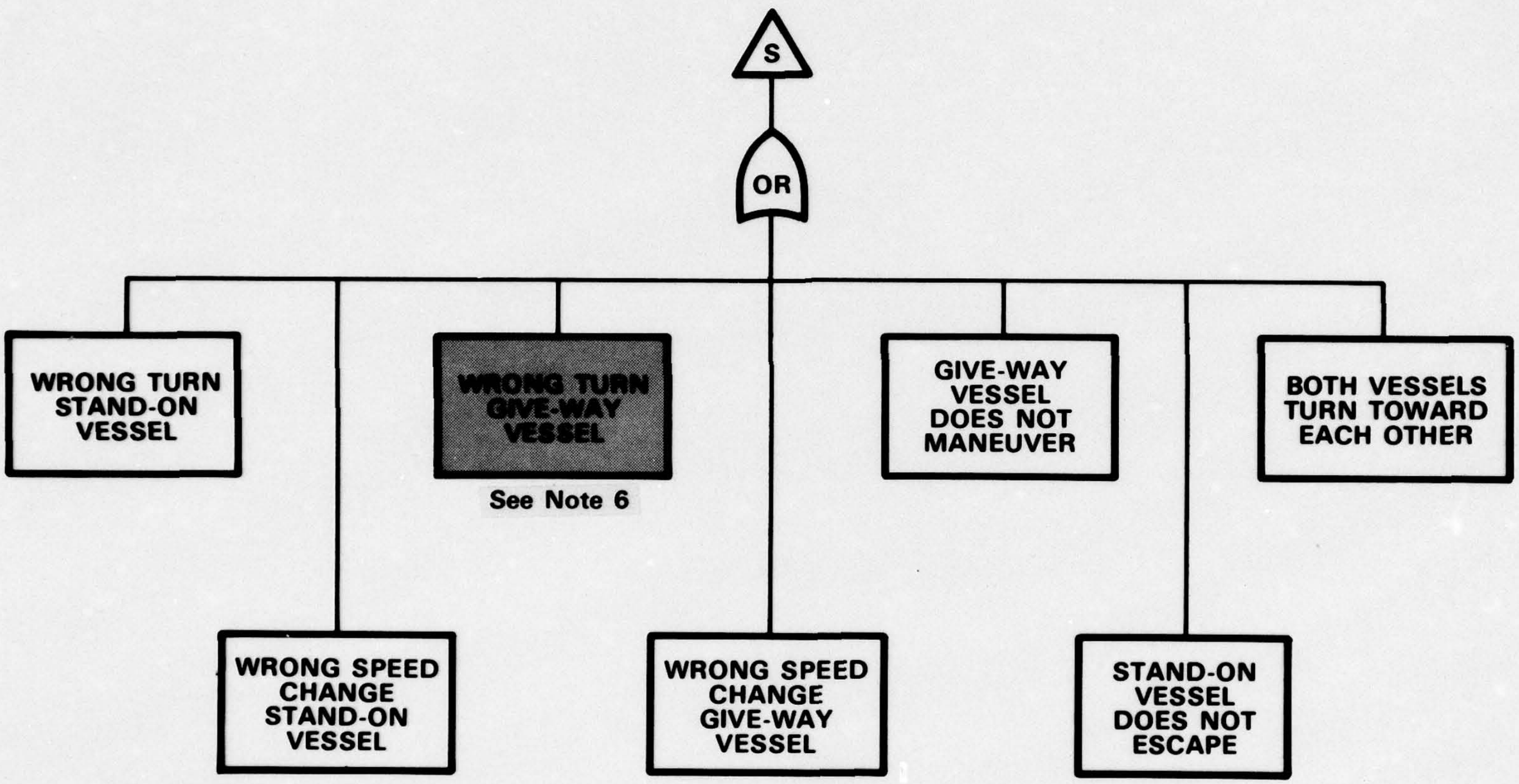
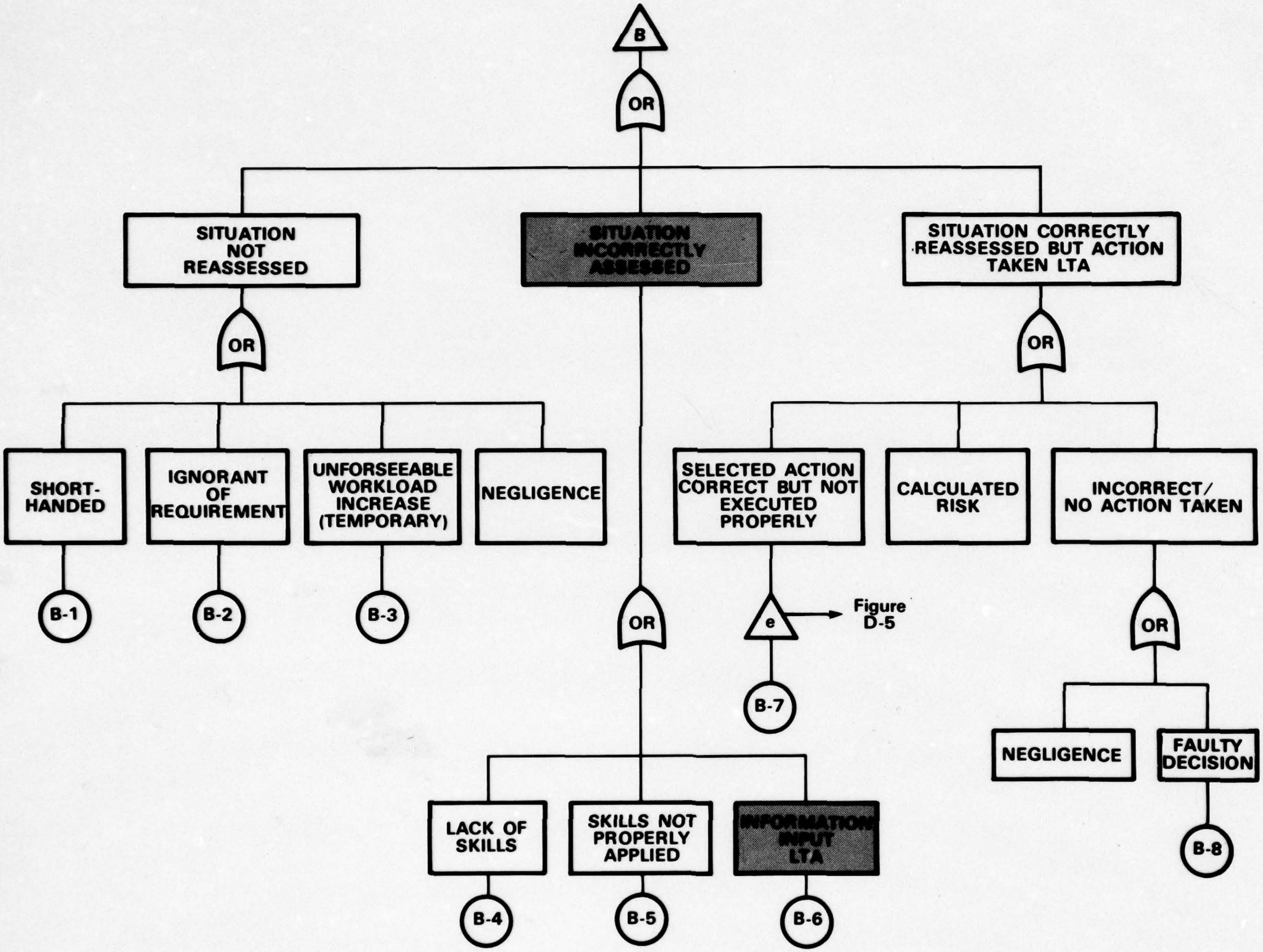


FIGURE D-4. EARLY ACTION LTA



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360

FIGURE D-14. PRECAUTIONS FOR TRAFFIC LTA

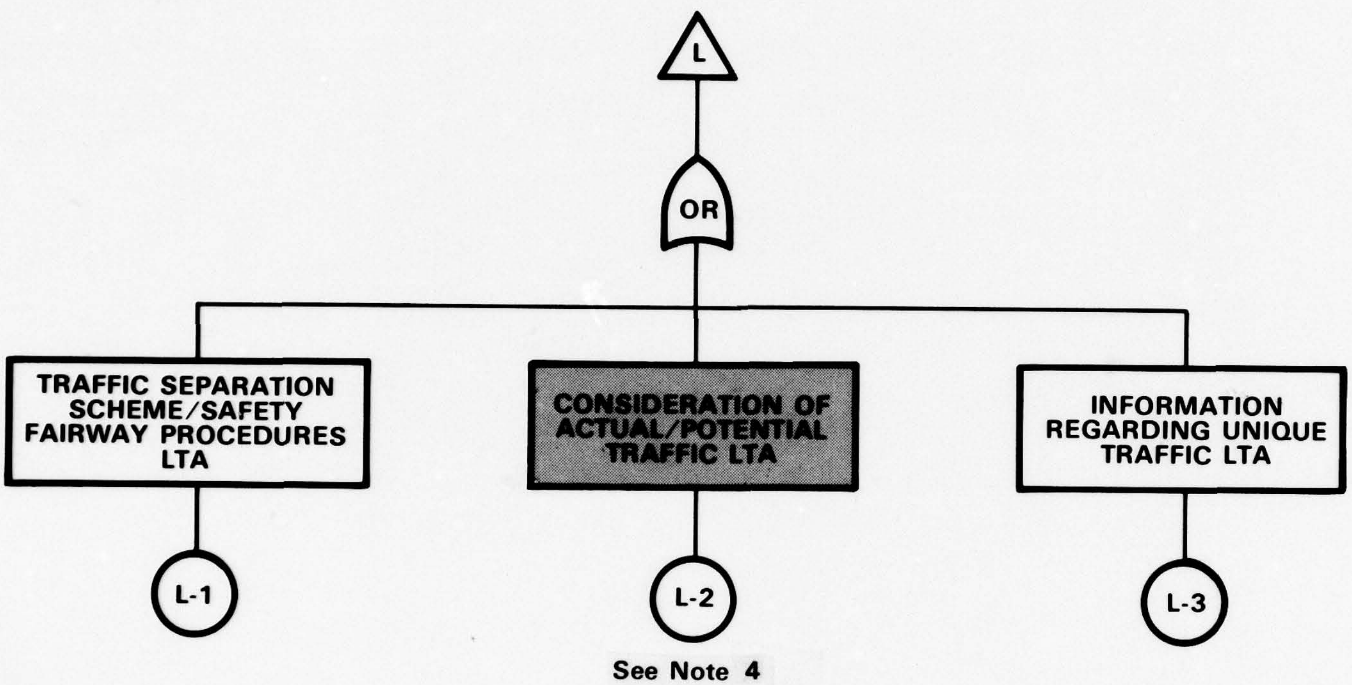


FIGURE D-17. ASSESSMENT OF ANGLE/DISTANCE TO OTHER VESSEL LTA

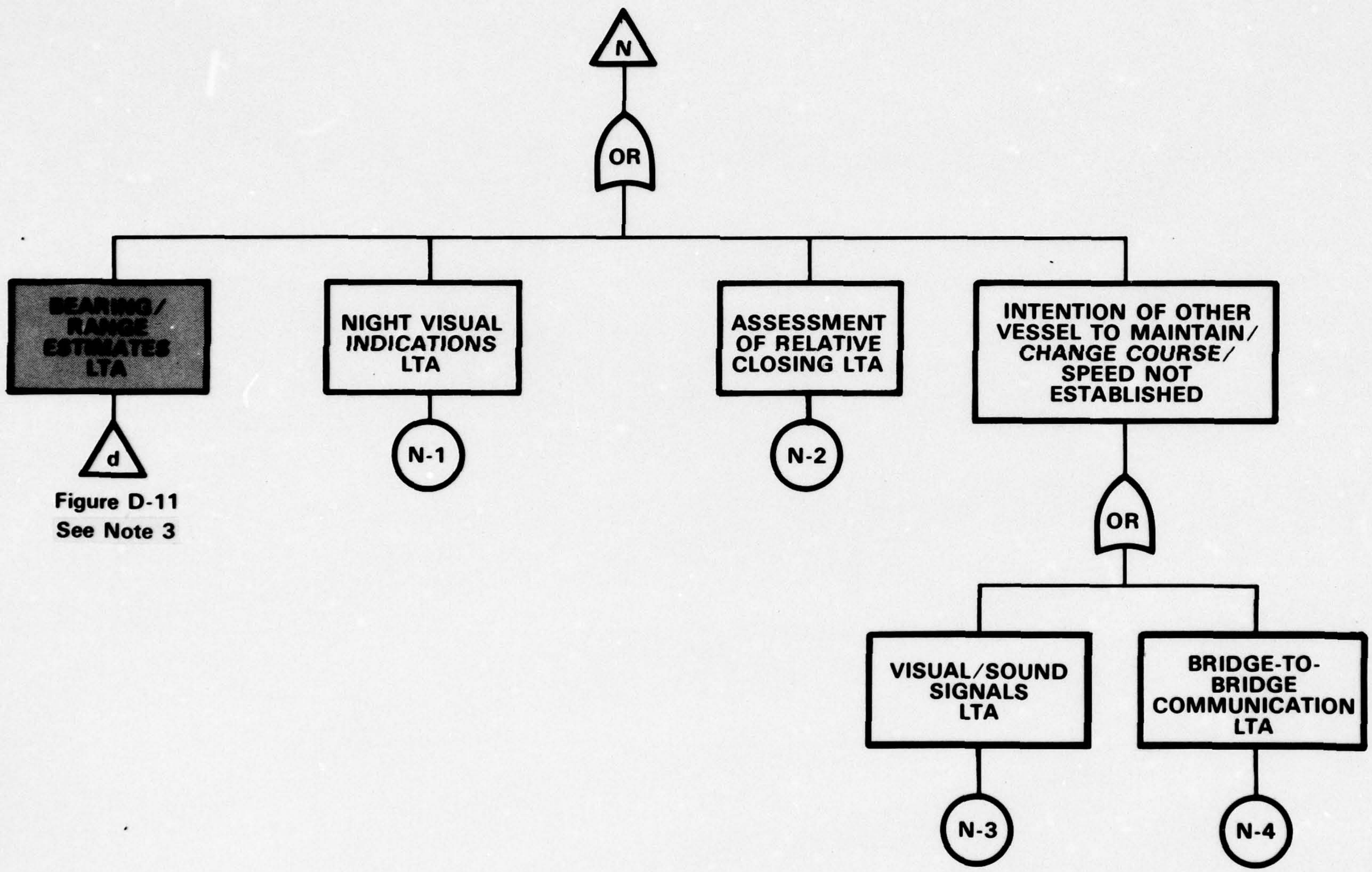
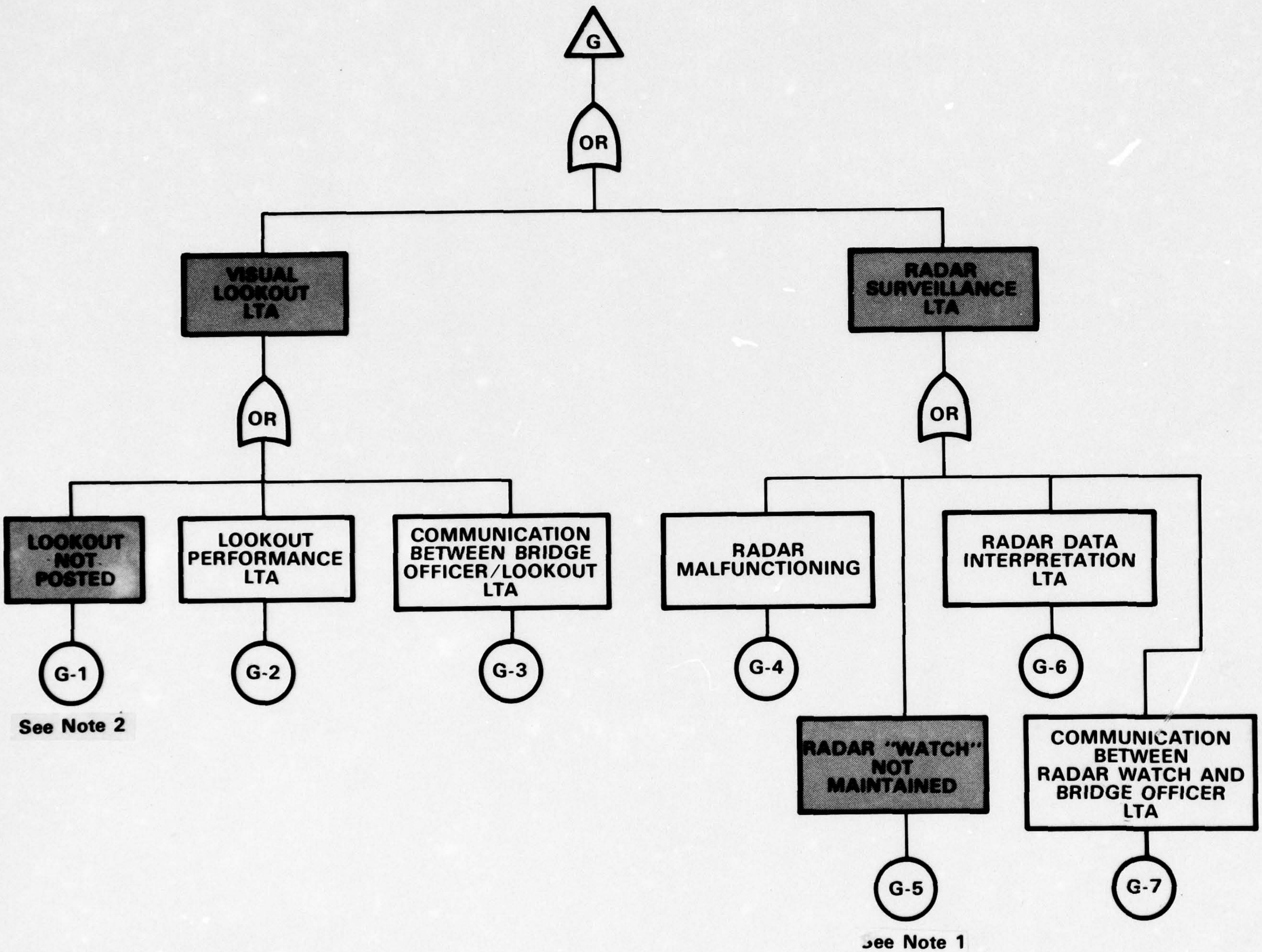


FIGURE D-9. VISUAL/RADAR LOOKOUT LTA



Appendix F

WEATHER AND CURRENT DATA

1. INTRODUCTION

The purpose of this appendix is to discuss the weather and currents in the Gulf of Mexico, its approaches, the Caribbean Sea, and the local weather and currents in the vicinity of LOOP and SEADOCK in order to assess how the operation of these two deepwater ports will be affected. Although both weather and current will have a direct effect on vessel operations in general, and selection of routes in particular, these aspects will not be discussed in any depth, since they are covered under the paper transit and actual ship transits sections of chapter VI, "Hazard Identification and Ranking." In like manner, weather broadcasts will not be discussed in this section since they are treated in the companion report on Technology/Service Alternatives.[1]

2. WEATHER

a. General

The weather in the Caribbean Sea and the Gulf of Mexico varies from tropical in the southern area, in which the northeast trade winds predominate at sea during most of the year, to the transition zone between a tropical and a temperate area in the north with more variable wind directions, mainly between north and southeast. In the water areas in the vicinity of the north coast of the Gulf of Mexico, northerly winds are rather frequent and may reach gale force at times. Over the open sea area of the northern Gulf of Mexico, wind speeds are mostly light to moderate with the exception of occasional hurricanes. There is much clear, sunny weather over the entire sea area, particularly in the trade wind portion. Sea fog seldom occurs in any part of the area; coastal fog, however, does occur occasionally in early spring near the northern shores of the Gulf. Statistics show an average of five hurricanes per year occur over some portion of the area during the period June to November. Hurricane tracks are fairly regular with most passing over the northeastern portion of the area as they veer to the north and northeast over Cuba. Not many hurricanes reach the western part of the Gulf of Mexico, and seldom do they go south of latitude 15° north.

Frost and snow occur occasionally along the northern coast of the Gulf of Mexico, otherwise the area is usually warm to very warm with high humidity.

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1. PRC Systems Services Company, Deepwater Ports Approach/Exit-Technology/Service Alternatives, prepared for the U.S. Coast Guard, February 1979.

There is a well-defined rainy season in the southern part of the area from May to December with frequent, heavy rain and thundershowers. Along the northern coast of the Gulf of Mexico there is substantial rain in all months, but July to October have the greatest amounts.

b. The LOOP AREA

The LOOP area, about 18 miles south of Bayou Lafourche, has a variable, warm, marine climate with weather patterns characteristic of the transition zone between a tropical and a temperate area. The Gulf of Mexico tends to modify the humidity and temperature with the result that long periods of unchanging humidity are frequent. The prevailing on-shore, moist winds during summer produce frequent thunderstorms. During winter there are alternating periods of cool, continental air and tropical air.

General air circulation in the area of LOOP is under the influence of the Bermuda High during the spring and summer. In autumn and winter, the high pressures over the North American continent predominate. In general, the lowest pressures occur in summer and the highest in winter. These pressure patterns produce prevailing southeasterly winds from March to August with the lowest average wind speeds for the year. This season also has the highest winds which occur during tropical cyclones. In autumn, these tropical winds change to prevailing northerlies under the influence of the cold high pressures to the north. Because of these northerly winds, winter has a higher average wind speed and the greatest incidence of winds in excess of 33 knots. It has been estimated that on the average there will be a maximum sustained wind speed of 95 knots in the LOOP area once every 10 years.[1] During the winter months extra tropical cyclones north of Bayou Lafourche occasionally bring strong northerly winds. There "northers" occur between October and February. During the period 1899 to 1971 in the LOOP area, a tropical cyclone occurred once every 1.6 years and a hurricane once every 4.1 years. Winds of 175 knots are estimated to have occurred in this area during hurricane Camille in August 1969.

The greatest rainfall occurs during the summer in the form of thunderstorms or convective showers although there is rainfall throughout the year. Heavy rains accompany tropical cyclones which occur occasionally in the area. Cold or warm front passage in the winter is usually accompanied by rain which is often slow, steady, and continuous, lasting for days at a time.

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1. U.S. National Oceanic and Atmospheric Administration, Environmental Guide for the U.S. Gulf Coast (Asheville, North Carolina: National Climatic Center, 1972), p.77.

Wave heights in this area are a function of the wind; heights greater than 11 feet have been observed in every month of the year. Wave heights of 20 feet or greater have been observed during tropical cyclones in the summer and "northers" in the winter. During hurricane Carla in September 1961, waves of over 30 feet were observed in the area. It has been estimated that, on the average, a maximum wave height of 34 feet will occur in the area once every 10 years.[1]

Fog occurs year around in the area with the least occurrence in summer and the greatest in winter and early spring. The month of February has the most number of foggy days.

The range of tides in the area is 1 to 1.5 feet which is, in general, diurnal. Winds and storms may cause wide variations in this range with major hurricanes causing water levels to rise 10 to 25 feet above mean sea level. There is a surface current flowing along the coast in a northwesterly to westerly direction at speeds of .7 to 1 knot.

There is relatively little seasonal variation in the monthly mean relative humidity which is fairly high throughout the year. Lowest humidities occur when the northern winds caused by the cold, dry continental highs blow in the winter. The highest humidities occur in the spring and summer when the warm, moist winds blow from over the Gulf of Mexico.

Tables F-1 through F-5 give environmental data based on marine observations in the Bayou Lafourche area (28°49'N, 90°04'W). This information is supplemented by a land station climatological summary for New Orleans which is 65 miles to the north of Bayou Lafourche.

c. The SEADOCK Area

The SEADOCK area, about 26 miles south of Freeport, Texas, has a warm and humid climate in summer which changes to moderately subtropical in the winter. The Gulf of Mexico has a moderating effect on the humidity and temperature, resulting in mild winters. Although summer days are warm and humid, the nights are relatively pleasant.

During the summer, warm humid air from the Gulf of Mexico brings showers and, occasionally, a tropical cyclone. Cold fronts in the winter which reach the area, while seldom very severe, produce low temperatures and strong cold winds

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1. U.S. National Oceanic and Atmospheric Administration, Environmental Guide for the U.S. Gulf Coast (Asheville, North Carolina: National Climatic Center, 1972), p.77.

STATION: NEW ORLEANS, LOUISIANA
POSITION: 29° 59'N 90° 15'W
ELEVATION: 4 FEET

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	25		25		(b)	(b)	25		25		25	
J	64.4	44.8	54.6	83	1957	14	1963+	363	3.84	12.62	1966	0.54	1968	4.77	1955
F	66.7	47.5	57.1	84	1948	19	1970+	258	3.99	10.56	1959	1.02	1962	5.60	1961
M	71.2	51.6	61.4	87	1963+	26	1968	192	5.34	19.09	1948	0.24	1955	7.87	1948
A	77.7	58.1	67.9	91	1948	32	1971	39	4.55	8.78	1949	0.33	1965	4.35	1953
M	84.4	64.4	74.4	96	1953+	41	1960	0	4.38	14.33	1959	0.99	1949	9.86	1959
J	89.6	70.5	80.1	100	1954	55	1966	0	4.43	8.87	1962	1.12	1952	4.19	1953
J	90.6	72.6	81.6	99	1951	60	1967	0	6.72	11.46	1954	3.45	1951	4.30	1966
A	90.7	73.0	81.9	100	1951	60	1968	0	5.34	11.77	1955	2.00	1952	3.06	1969
S	87.2	69.3	78.3	97	1954+	42	1967	0	5.03	16.74	1971	0.24	1953	6.50	1971
O	80.3	60.5	70.4	92	1962+	35	1968	19	2.84	6.45	1959	0.00	1952	2.58	1960
N	70.3	49.6	60.0	86	1951	24	1970	192	3.34	14.58	1947	0.21	1949	6.38	1953
D	65.3	45.5	55.4	84	1971	17	1962	322	4.10	10.77	1967	1.46	1958	3.94	1952
YR	78.2	59.0	68.6	100	JUN. 1954+	14	JAN. 1963+	1385	53.90	19.09	MAR. 1948	0.00	OCT. 1952	9.86	MAY 1959

Month	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset
(a)	25	25		25		23	23	23	23	23		12	12			23
J	T	T	1969+	T	1969+	84	86	67	73	9.6		33	28	1966		6.7
F	0.1	2.0	1958	2.0	1958	82	85	63	68	10.2		43	26	1970		6.2
M	T	T	1959	T	1959	82	84	60	64	10.2		37	18	1969		6.1
A	0.0	0.0		0.0		85	88	60	66	9.6		35	07	1960		5.7
M	0.0	0.0		0.0		86	89	59	65	8.3		31	23	1962		5.1
J	0.0	0.0		0.0		87	90	62	67	6.9		48	05	1971		5.0
J	0.0	0.0		0.0		89	91	66	73	6.3		32	07	1969		6.1
A	0.0	0.0		0.0		89	91	66	73	6.2		42	33	1969		5.5
S	0.0	0.0		0.0		87	89	65	74	7.5		69	09	1965		5.2
O	0.0	0.0		0.0		84	87	59	72	7.7		40	17	1964		4.1
N	T	T	1950	T	1950	83	86	59	74	8.9		30	31	1969		4.9
D	0.1	2.7	1963	2.7	1963	83	86	67	75	9.2		32	17	1969		6.2
YR	0.2	2.7	DEC. 1963	2.7	DEC. 1963	85	88	63	70	8.4		69	09	SEP. 1965		5.6

Month	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max.: 90° and above ‡	Max.: 32° and below	Min.: 32° and below	Min.: 0° and below	Average daily solar radiation - langleys
(a)	23	23	23	23	23	23	23	25	25	25	25	
J	7	8	16	9	0	1	7	0	*	5	0	
F	8	6	14	9	*	2	5	0	0	3	0	
M	8	9	14	9	0	3	4	0	0	1	0	
A	8	11	11	7	0	4	2	*	0	*	0	
M	11	11	9	8	0	6	1	4	0	0	0	
J	10	13	7	10	0	9	*	17	0	0	0	
J	5	16	10	15	0	16	*	20	0	0	0	
A	9	13	9	13	0	13	*	19	0	0	0	
S	11	10	9	10	0	7	*	8	0	0	0	
O	16	7	8	6	0	2	2	1	0	0	0	
N	12	8	10	6	0	1	4	0	0	1	0	
D	8	8	15	10	*	2	5	0	*	3	0	
YR	113	120	132	112	*	68	31	48	*	12	0	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 102 in June 1954 and earlier (City Office); lowest temperature 7 in February 1899; maximum monthly precipitation 25.11 in October 1937; maximum precipitation in 24 hours 14.01 in April 1927; maximum monthly snowfall 8.2 in February 1895; maximum snowfall in 24 hours 8.2 in February 1895.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

SOURCE: U.S. National Oceanic and Atmospheric Administration. *Environmental Guide for the Gulf Coast*; Asheville, N.C.: National Climatic Center, 1972.

TABLE F-1. LAND STATION CLIMATOLOGICAL DATA SUMMARY FOR NEW ORLEANS, LOUISIANA.

~~369~~ 368

ENVIRONMENTAL DATA SUMMARY (PART 1)

AREA: Bayou Lafourche — CENTRAL POSITION: 28° 49'N 90° 04'W

ENVIRONMENTAL FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
WIND SPEED (KNOTS)													
01% ≤	0	0	0	0	0	0	0	0	0	0	0	0	0
05% ≤	3	4	2	2	1	1	1	1	1	1	1	4	1
25% ≤	7	6	6	6	5	4	4	4	5	6	7	6	6
50% ≤	12	12	11	11	9	8	7	7	9	11	12	12	9
75% ≤	18	18	17	17	15	12	10	11	16	16	18	18	16
95% ≤	28	28	27	25	21	20	19	19	25	24	28	28	25
99% ≤	35	35	35	30	25	25	22	24	33	30	33	33	30
Maximum observed	Winds in excess of 150 knots are estimated to have occurred during great hurricanes.												
Mean	13.3	13.3	12.9	12.4	10.4	9.0	8.1	8.5	11.4	11.9	13.1	13.4	11.5
≥ 34 Knots (% freq.)	1.1	1.0	1.1	0.6	0.1	0.2	0.1	0.2	0.9	0.5	0.9	0.9	0.6
≥ 41 Knots (% freq.)	0.1	0.1	0.1	0.2	+	+	+	0.1	0.2	0.1	+	0.2	0.1
Prevailing direction	N	E	SE	SE	SE	SE	SE	SE	E	NE	N	E	SE
SEA-LEVEL PRESSURE (mb)													
Minimum observed	1001	996	998	998	999	1000	1001	1001	984	1003	1000	998	984
01% ≤	1008	1003	1004	1004	1006	1007	1010	1010	1006	1007	1006	1008	1006
05% ≤	1011	1007	1008	1008	1009	1011	1013	1012	1009	1011	1011	1011	1010
25% ≤	1017	1015	1013	1013	1014	1014	1016	1014	1013	1014	1016	1017	1015
50% ≤	1021	1019	1017	1017	1016	1016	1017	1016	1015	1017	1019	1020	1018
75% ≤	1024	1022	1021	1020	1018	1018	1019	1018	1017	1019	1022	1024	1020
95% ≤	1028	1027	1026	1024	1021	1020	1021	1020	1019	1023	1026	1028	1024
99% ≤	1032	1033	1029	1027	1024	1022	1023	1022	1021	1026	1030	1033	1027
Maximum observed	1037	1041	1034	1032	1028	1032	1030	1031	1029	1035	1037	1037	1041
Mean	1020	1018	1017	1016	1016	1016	1017	1016	1015	1017	1019	1020	1017
WEATHER & CLOUDS (% FREQ.)													
Precipitation	3.1	4.9	3.3	2.2	2.2	2.1	2.9	3.5	3.9	3.0	3.4	3.6	3.2
Freezing precipitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Frozen precipitation	0.0	+	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	+	0.0	+
Thunder & lightning	0.6	0.8	0.9	1.0	1.1	1.2	3.0	2.1	1.4	0.8	0.5	0.6	1.2
Sky ≤2/8	32.7	33.4	36.3	41.0	46.4	42.9	33.4	33.6	32.8	45.8	37.9	32.4	37.4
Low cloud overcast	17.2	18.0	14.1	7.9	5.3	2.1	2.7	3.1	6.0	6.3	11.2	13.2	8.9
Total sky overcast	25.8	27.1	23.3	16.5	9.8	6.9	8.4	9.7	13.4	12.5	19.6	23.2	16.4
Sky obscured	1.2	1.4	1.2	1.0	0.1	0.2	0.2	0.1	0.4	0.1	0.2	1.2	0.6
Mean cloud cover (eighths)	4.5	4.5	4.2	3.7	3.3	3.3	3.8	3.8	4.0	3.4	4.0	4.4	3.9
VISIBILITY (% FREQ.)													
Visibility <½ N. mile	1.1	1.0	1.1	0.4	+	+	0.1	+	0.1	0.2	0.1	0.3	0.4
Visibility <1 N. mile	1.5	1.3	1.4	0.4	+	0.1	0.2	0.1	0.1	0.2	0.1	0.6	0.6
Visibility <2 N. mile	2.0	1.9	1.7	0.6	0.1	0.2	0.6	0.2	0.3	0.4	0.3	0.7	0.9
Visibility <5 N. mile	3.8	4.6	5.0	2.7	0.9	1.4	1.1	0.7	1.2	1.4	1.5	2.3	2.4
Visibility <10 N. mile	18.1	22.7	27.0	23.3	13.8	8.8	4.8	5.9	10.7	10.2	13.0	16.5	14.8
FOG													
Occurrence of fog (% freq.)	3.1	3.6	4.2	1.8	0.3	+	0.1	0.1	0.1	0.2	0.3	1.8	1.3
Mean number of hours operation of fog signals*													
Maximum numbers of hours operation of fog signals for any year (annual only)*													

+ = Less than 0.05%. * Data not available. **Source: Same as Table F-1**

TABLE F-2. ENVIRONMENTAL DATA SUMMARY; BAYOU LAFOURCHE AREA.

ENVIRONMENTAL DATA SUMMARY (PART 2)

AREA: Bayou Lafourche

CENTRAL POSITION: 28° 49'N 90° 04'W

ENVIRONMENTAL FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
WAVES (FEET)													
01% ≤	1	1	1	1	1	1	1	1	1	1	1	1	1
05% ≤	1	1	1	1	1	1	1	1	1	1	1	1	1
25% ≤	2	2	2	2	1	1	1	1	1	1	2	2	1
50% ≤	4	4	4	4	3	2	2	2	3	3	4	4	3
75% ≤	6	6	6	5	4	4	3	3	5	5	6	6	5
95% ≤	9	9	9	8	7	6	6	6	8	7	9	9	8
99% ≤	13	13	13	12	10	8	8	7	12	10	12	12	12
Maximum observed	25	23	21	16	13	21	13	13	31	18	25	20	31
Mean	4	4	4	4	3	2	2	2	3	3	4	4	3
≥ 5 Feet (% freq.)	37.4	39.1	38.7	33.9	22.9	14.3	8.6	11.5	27.0	28.6	35.7	37.5	28.0
≥ 8 Feet (% freq.)	8.0	9.3	8.7	6.1	3.5	1.3	1.1	1.0	6.2	4.6	7.5	8.5	5.5
≥ 12 Feet (% freq.)	2.2	2.9	2.0	1.1	0.5	0.3	0.2	0.2	1.6	0.6	1.9	1.8	1.3
≥ 20 Feet (% freq.)	0.1	0.1	0.1	0.0	0.0	+	0.0	0.0	0.2	0.0	0.1	0.1	0.1
RELATIVE HUMIDITY (%)													
Mean	79	80	80	81	81	78	77	77	78	75	76	78	78
AIR TEMPERATURE (°F)													
Minimum observed	30	32	37	46	58	67	70	70	62	52	39	36	30
01% ≤	42	44	48	58	67	74	77	76	72	60	49	45	59
05% ≤	49	50	54	62	70	77	80	79	76	67	55	51	64
25% ≤	56	57	60	66	73	79	82	81	79	71	62	58	68
50% ≤	64	65	67	72	77	82	84	84	82	77	71	67	74
75% ≤	70	70	71	76	81	85	87	87	85	81	75	72	78
95% ≤	75	74	75	79	84	88	90	90	88	84	79	76	82
99% ≤	78	78	80	83	88	92	94	94	92	88	83	79	86
Maximum observed	84	85	88	91	94	99	100	100	99	99	90	90	100
Mean	63.2	63.8	66.1	71.4	77.4	82.0	84.1	84.0	81.9	76.7	69.8	65.5	74.3
≥ 32 °F (% freq.)	0.1	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+
≥ 85 °F (% freq.)	0.0	+	+	0.7	4.0	21.4	40.4	39.8	18.2	3.9	0.5	0.1	10.8
SEA TEMPERATURE (°F)													
Minimum observed	44	39	41	56	62	63	68	69	66	63	57	49	39
01% ≤	54	45	52	62	68	76	80	79	77	70	64	58	58
05% ≤	59	58	61	65	72	78	81	82	80	75	68	63	64
25% ≤	65	65	66	69	75	81	84	84	82	79	73	68	70
30% ≤	69	68	68	71	77	82	85	85	84	80	76	71	78
75% ≤	71	70	70	74	79	84	86	87	85	82	78	74	83
95% ≤	75	75	74	77	82	86	88	88	87	85	80	77	87
99% ≤	78	78	79	80	84	88	90	90	88	86	82	80	89
Maximum observed	84	83	84	86	91	92	94	94	92	90	88	87	94
Mean	68.1	67.1	68.0	71.3	77.0	82.2	85.2	85.4	83.9	80.3	75.2	70.9	76.2
SALINITY (‰)													
Minimum observed	28.0	30.6	24.6	30.0	29.2	27.8	28.5	29.0	32.4	32.5	33.0	31.0	24.6
Mean	32.7	34.4	33.5	33.0	32.7	32.5	32.9	33.2	33.6	34.2	35.8	34.6	33.6
Maximum observed	36.6	36.3	36.3	36.4	36.5	36.0	35.5	35.0	34.7	35.0	36.0	35.6	36.6
DENSITY (ρ)													
Mean (σ_t)*	22.9	24.5	23.5	25.1	23.0	22.5	22.1	21.7	21.1	21.3	21.5	21.8	22.6

+ = Less than 0.05%. * $\sigma_t = (\rho - 1) \times 10^3; \rho = \text{gm cm}^{-3}$.

TABLE F-2. (continued)

83

370

AREA: Bayou Lafourche

CENTRAL POSITION: 28° 49'N 90° 04'W

JANUARY — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.3	4.5	8.6	2.7	.2	.0		16.4	15.3
NE	.3	5.7	8.6	1.6	.1	.0		16.3	14.0
E	.8	6.5	8.3	.6	.2	.0		16.3	12.4
SE	.9	7.0	6.2	.6	*	.0		14.7	11.4
S	.7	6.5	5.5	.8	.1	.0		13.5	11.6
SW	.3	2.5	2.3	.1	*	.0		5.3	11.3
W	.1	1.8	2.3	1.1	.3	.0		5.6	16.3
NW	.1	2.5	4.6	2.5	.4	.0		10.1	17.3
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	1.8							1.8	.0
TOT OBS	135	946	1191	260	29	0	2561		13.3
TOT PCT	5.3	36.9	46.5	10.2	1.1	.0		100.0	

FEBRUARY — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.4	4.0	7.0	2.2	.3	.0		13.9	15.4
NE	.2	4.7	8.1	2.4	.2	*		15.7	15.2
E	.4	6.6	7.9	1.1	*	.0		16.0	13.0
SE	.7	7.1	6.9	.8	*	.0		15.4	11.9
S	.6	6.8	6.6	.5	.1	.0		14.6	11.7
SW	.2	3.6	2.7	.4	*	.0		7.0	11.6
W	.1	2.9	2.7	.8	.1	.0		6.6	13.9
NW	.2	2.4	4.7	1.8	.2	.0		9.4	15.8
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	1.5							1.5	.0
TOT OBS	105	956	1167	253	24	1	2506		13.3
TOT PCT	4.2	38.1	46.6	10.1	1.0	*		100.0	

MARCH — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.5	3.4	6.3	2.3	.3	.0		12.7	15.4
NE	.4	5.3	7.3	1.2	.1	.0		14.4	13.3
E	.5	6.3	7.4	.9	.1	.0		15.2	12.5
SE	1.3	8.9	11.0	.6	.0	.0		21.9	11.8
S	.7	6.4	6.2	.9	*	*		14.4	12.1
SW	.2	2.6	1.8	.3	*	.0		4.9	11.1
W	.4	1.8	1.9	.7	.2	*		5.0	14.2
NW	.4	2.6	4.4	1.8	.3	.0		9.4	16.1
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.2							2.2	.0
TOT OBS	187	1056	1313	248	28	2	2834		12.9
TOT PCT	6.6	37.3	46.3	8.8	1.0	.1		100.0	

APRIL — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.5	3.0	4.2	1.0	.3	.0		9.0	14.3
NE	.5	3.8	5.4	.9	.0	.0		10.6	13.2
E	.5	8.7	10.2	.9	.0	.0		20.4	11.9
SE	.8	12.0	14.1	1.0	.1	.0		28.1	12.3
S	.7	6.7	7.2	.9	.1	.0		15.6	12.4
SW	.4	2.3	1.6	.1	.0	.0		4.5	9.9
W	.2	1.8	1.8	.3	.1	*		4.2	13.5
NW	.1	1.3	2.8	1.2	.1	.0		5.5	16.3
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.2							2.2	.0
TOT OBS	154	1030	1229	168	15	1	2597		12.4
TOT PCT	5.9	39.7	47.3	6.5	.6	*		100.0	

MAY — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.8	2.8	2.2	.5	*	.0		6.4	11.4
NE	.6	5.1	3.1	.5	*	.0		9.5	10.8
E	1.3	9.0	8.4	.7	*	.0		19.3	11.2
SE	1.3	13.8	13.9	.6	.0	.0		29.5	11.3
S	.8	8.0	6.4	.6	.0	.0		15.8	10.8
SW	.7	3.9	1.7	.1	.0	.0		6.4	9.2
W	.4	2.8	1.5	.0	.0	.0		4.7	9.2
NW	.6	2.8	1.1	.1	.0	.0		4.5	8.7
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	3.9							3.9	.0
TOT OBS	279	1299	1033	84	3	0	2698		10.4
TOT PCT	10.3	48.1	38.3	3.1	.1	.0		100.0	

JUNE — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.8	2.2	.6	.1	.0	.0		3.8	7.6
NE	.7	3.3	1.5	.2	.0	.0		5.6	9.1
E	1.4	9.5	4.7	.4	.0	.0		16.0	9.6
SE	1.7	14.6	9.8	.5	.1	.0		26.6	10.4
S	2.2	12.7	6.6	.5	*	.0		22.0	9.6
SW	.8	5.5	2.6	.1	*	.0		9.0	9.3
W	.7	4.0	1.9	.1	*	.0		6.7	8.9
NW	.6	3.5	.5	.1	.0	.0		4.7	7.8
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	5.7							5.7	.0
TOT OBS	443	1698	869	56	5	0	3071		9.0
TOT PCT	14.4	55.3	28.3	1.8	.2	.0		100.0	

JULY — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.7	2.1	.7	*	.0	.0		3.6	7.9
NE	.5	2.6	.9	*	.0	.0		4.1	8.0
E	1.3	8.1	3.6	.1	.1	.0		13.2	9.1
SE	1.7	13.0	5.7	.2	.0	.0		20.6	9.3
S	2.5	12.9	4.8	.3	*	.0		20.5	8.7
SW	.9	8.8	2.5	*	.0	.0		12.3	8.4
W	1.3	8.3	2.1	.1	.0	.0		11.9	8.2
NW	.7	3.9	1.7	*	.0	.0		6.4	8.9
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	7.4							7.4	.0
TOT OBS	521	1834	680	29	3	0	3067		8.1
TOT PCT	17.0	59.8	22.2	.9	.1	.0		100.0	

AUGUST — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.1	3.4	1.4	.1	.0	.0		5.9	8.2
NE	.8	4.5	2.7	.1	*	*		8.1	9.9
E	1.7	10.3	5.2	.2	*	*		17.4	9.6
SE	1.5	11.9	5.3	.1	.0	.0		18.8	9.2
S	1.8	11.0	4.0	.2	*	.0		17.0	8.7
SW	1.1	7.0	2.6	.2	*	.0		10.9	9.1
W	.8	6.2	2.3	.1	*	.0		9.4	8.9
NW	.8	4.1	1.3	.1	.0	.0		6.3	8.3
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	6.1							6.1	.0
TOT OBS	472	1766	751	35	3	2	3029		8.5
TOT PCT	15.6	58.3	24.8	1.2	.1	.1		100.0	

SEPTEMBER — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.5	4.1	3.7	.5	.1	.0		8.8	11.8
NE	.8	7.7	8.9	1.8	.1	.1		19.2	13.0
E	1.4	12.2	12.8	2.1	.3	*		28.9	12.4
SE	.6	9.3	7.5	.9	.2	.0		18.5	11.7
S	1.1	5.0	3.3	.5	.2	*		10.1	11.2
SW	.5	2.2	1.1	.1	.0	*		3.9	9.7
W	.6	2.4	.9	*	.0	.0		3.9	7.8
NW	.4	2.1	.8	.1	.0	.0		3.4	9.6
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	3.2							3.2	.0
TOT OBS	267	1336	1160	180	24	4	2971		11.4
TOT PCT	9.0	45.0	39.0	6.1	.8	.1		100.0	

OCTOBER — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.8	6.3	7.6	1.7	.1	.0		16.5	13.1
NE	.7	10.5	12.5	1.7	.2	*		25.6	12.8
E	.7	11.0	11.8	1.5	.2	.0		25.2	12.4
SE	.5	6.5	5.6	.6	.1	.0		13.2	11.5
S	.6	2.9	1.9	.2	.0	.0		5.5	9.9
SW	.3	1.4	1.0	.1	.0	.0		2.8	10.0
W	.4	1.4	.7	.2	.0	.0		2.6	9.5
NW	.1	2.7	3.0	.4	.0	.0		6.3	12.6
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.4							2.4	.0
TOT OBS	186	1243	1277	183	15	1	2905		11.9
TOT PCT	6.4	42.8	44.0	6.3	.5	*		100.0	

NOVEMBER — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.6	5.2	9.0	3.6	.3	.0		18.7	15.6
NE	.4	7.3	8.2	1.7	.2	.0		17.9	13.4
E	.6	7.9	8.7	1.1	*	.0		18.3	12.4
SE	.5	6.2	7.9	.8	*	.0		15.5	12.6
S	.4	4.3	4.9	.8	.1	.0		10.6	12.8
SW	.1	2.6	1.7	.2	*	.0		4.6	11.4
W	.4	2.0	1.4	.2	*	.0		4.0	10.6
NW	.5	2.2	4.4	1.3	.1	.0		8.4	15.0
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	1.9							1.9	.0
TOT OBS	139	957	1176	248	22	0	2542		13.1
TOT PCT	5.5	37.6	46.3	9.8	.9	.0		100.0	

DECEMBER — WIND SPEED (KNOTS)

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
N	.6	5.3	7.3	3.0	.3	.0		16.6	15.2
NE	.4	5.7	8.8	1.9	.1	.0		17.0	14.1
E	.4	7.4	8.8	.7	.0	.0		17.3	12.4
SE	.6	6.5	7.6	.8	.2	.0		15.7	12.8
S	.7	5.7	6.0	1.1	*	.0		13.5	12.4
SW	.2	2.6	1.9	.3	.0	.0		5.0	10.9
W	.1	2.0	2.0	.6	.0	.0		4.8	13.4
NW	.1	2.2	4.4	1.9	.3	.0		8.9	16.8
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	1.2							1.2	.0
TOT OBS	112	960	1199	267	23	0	2561		13.4
TOT PCT	4.4	37.5	46.8	10.4	.9	.0		100.0	

Source: Same as Table F-1

TABLE F-3. MONTHLY SUMMARIES WIND DIRECTION AND SPEED (PERCENTAGE FREQUENCY) BASED ON MARINE OBSERVATIONS.

AREA: Bayou Lafourche CENTRAL POSITION: 28° 49'N 90° 04'W

JANUARY — PRECIPITATION TYPE / OTHER WEATHER PHENOMENA

WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.0	.3	.0	.0	.0	.0	.4		.1	.4	.3	.0	14.5	
NE	.3	.1	.2	.0	.0	.0	.0	.6		.0	.7	.3	.0	14.6	
E	.4	.1	.3	.0	.0	.0	.0	.8		*	.5	.6	.0	14.9	
SE	.3	.1	.1	.0	.0	.0	.0	.6		*	.6	.7	.0	13.0	
S	.2	.0	.1	.0	.0	.0	.0	.3		.3	.4	1.1	.0	12.1	
SW	.1	*	*	.0	.0	.0	.0	.1		.0	.1	.4	.0	4.7	
W	.1	.1	.0	.0	.0	.0	.0	.2		.1	.1	.2	.0	5.2	
NW	.1	*	*	.0	.0	.0	.0	.2		*	.1	.2	.0	9.5	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.2	.1	.0	1.0	
TOT OBS	38	10	23	0	0	0	0		69	13	69	87	0	1999	2234
TOT PCT	1.7	.4	1.0	.0	.0	.0	.0	3.1		.6	3.1	3.9	.0	89.5	

FEBRUARY — PRECIPITATION TYPE / OTHER WEATHER PHENOMENA

WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.3	.2	.2	.0	*	.0	.0	.7		*	.2	.7	.1	11.6	
NE	.5	.1	.4	.0	.0	.0	.0	1.0		.1	.2	.7	*	13.6	
E	.7	.3	.3	.0	.0	.0	.0	1.1		.1	.2	.7	.0	13.8	
SE	.3	.1	.3	.0	.0	.0	.0	.6		.2	1.0	1.3	.0	12.5	
S	.1	.1	.1	.0	.0	.0	.0	.3		.1	1.1	1.5	.0	11.9	
SW	.2	*	.2	.0	.0	.0	*	.3		.2	.3	.4	.0	5.9	
W	.1	.0	.1	.0	.0	.0	*	.2		.1	.1	.2	*	6.1	
NW	.2	*	.2	.0	.0	.0	.0	.4		.0	.1	.5	.1	8.1	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.1	.0	.0	.0	.0	.1		.0	.3	.2	.0	.8	
TOT OBS	52	20	43	0	1	0	1		108	18	78	138	7	1870	2217
TOT PCT	2.3	.9	1.9	.0	*	.0	*	4.9		.8	3.5	6.2	.3	84.3	

MARCH — PRECIPITATION TYPE / OTHER WEATHER PHENOMENA

WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.2	*	*	.0	.0	.0	.0	.2		.2	.1	.5	.1	12.0	
NE	.6	*	.5	.0	.0	.0	.0	.8		.1	.4	.4	*	12.4	
E	.4	*	.2	.0	.0	.0	.0	.6		.2	.4	.9	*	12.9	
SE	.3	.0	.4	.0	.0	.0	.0	.6		.1	1.2	2.2	.0	17.3	
S	.4	*	.1	.0	.0	.0	.0	.5		.1	.7	2.0	*	11.4	
SW	*	.1	.0	.0	.0	.0	.0	.2		.1	.4	.5	*	4.1	
W	.1	.0	.1	.0	.0	.0	.0	.2		*	.1	.4	.0	4.3	
NW	.1	*	.1	.0	.0	.0	.0	.2		*	.4	.3	*	8.7	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	*	.0	.0	.0	.0	*		.0	.3	.2	.0	1.2	
TOT OBS	49	7	34	0	0	0	0		83	22	103	183	7	2101	2494
TOT PCT	2.0	.3	1.4	.0	.0	.0	.0	3.3		.9	4.1	7.3	.3	84.2	

APRIL — PRECIPITATION TYPE / OTHER WEATHER PHENOMENA

WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.2	*	.1	.0	.0	.0	.0	.3		*	.1	.4	.0	8.0	
NE	.3	.1	.1	.0	.0	.0	.0	.4		.2	.2	.4	.0	9.1	
E	.3	.1	*	.0	.0	.0	.0	.5		.1	.3	1.4	.0	18.1	
SE	.4	*	.2	.0	.0	.0	.0	.6		.2	.4	4.1	*	23.1	
S	.2	*	*	.0	.0	.0	.0	.3		.2	.3	3.1	.0	12.2	
SW	.1	.1	.0	.0	.0	.0	.0	.1		.1	.2	.5	.0	3.6	
W	.0	.0	.0	.0	.0	.0	.0	.0		.1	.2	.5	.0	3.4	
NW	.0	.0	.0	.0	.0	.0	.0	.0		.0	*	.2	.1	5.1	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.1	*	.0	1.8	
TOT OBS	34	8	10	0	0	0	0		51	23	41	245	3	1948	2306
TOT PCT	1.5	.3	.4	.0	.0	.0	.0	2.2		1.0	1.8	10.6	.1	84.5	

MAY — PRECIPITATION TYPE / OTHER WEATHER PHENOMENA

WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	*	.0	.0	.0	.0	.0	.2		.0	.0	.3	.0	6.0	
NE	.1	*	.1	.0	.0	.0	.0	.2		.1	.0	.4	*	8.9	
E	.2	.2	.3	.0	.0	.0	.0	.7		.1	.1	1.2	.1	17.3	
SE	.3	.1	.2	.0	.0	.0	.0	.5		.4	.1	2.1	.0	26.9	
S	.2	*	.0	.0	.0	.0	*	.2		.2	.0	1.2	.0	14.4	
SW	*	.1	*	.0	.0	.0	.0	.1		.2	.0	.6	.0	5.3	
W	*	*	.0	.0	.0	.0	.0	.1		.1	.0	.2	.0	4.1	
NW	*	*	.0	.0	.0	.0	.0	.1		.0	.0	.5	.0	3.6	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	*	.0	.0	.0	.0	*		.0	*	.4	.0	2.9	
TOT OBS	23	12	16	0	0	0	1		51	26	6	164	2	2113	2360
TOT PCT	1.0	.5	.7	.0	.0	.0	*	2.2		1.1	.3	6.9	.1	89.5	

JUNE — PRECIPITATION TYPE / OTHER WEATHER PHENOMENA

WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	*	.1	*	.0	.0	.0	.0	.2		.1	.0	.2	.0	3.5	
NE	.0	*	*	.0	.0	.0	.0	*		.1	.0	.3	.0	5.1	
E	.1	.1	.1	.0	.0	.0	.0	.3		.2	.0	.4	.0	15.0	
SE	.4	.1	.1	.0	.0	.0	.0	.5		.2	.0	.6	.0	25.3	
S	.3	.2	.1	.0	.0	.0	.0	.6		.3	*	.7	.0	20.6	
SW	.1	*	*	.0	.0	.0	.0	.1		.1	.0	.3	.0	8.5	
W	.1	*	*	.0	.0	.0	.0	.1		.1	.0	.2	.0	6.0	
NW	.1	.1	.0	.0	.0	.0	.0	.2		.1	.0	.4	.0	4.0	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	*	.0	*	.0	.0	.0	.0	*		.1	.0	.3	.0	5.3	
TOT OBS	31	19	10	0	0	0	0		57	33	1	102	0	2622	2813
TOT PCT	1.1	.7	.4	.0	.0	.0	.0	2.0		1.2	*	3.6	.0	93.2	

Source: Same as Table F-1

TABLE F-4. MONTHLY SUMMARIES OF WEATHER OCCURRENCE BY WIND DIRECTION (PERCENTAGE FREQUENCY) BASED ON MARINE OBSERVATIONS.

AREA: Bayou Lafourche

CENTRAL POSITION: 28° 49'N 90° 04'W

JULY WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	*	*	*	.0	.0	.0	.0	.1		.1	*	.1	.0	3.4	
NE	.2	*	*	.0	.0	.0	.0	.2		.2	*	.2	.0	3.4	
E	.2	.3	*	.0	.0	.0	.0	.5		.5	.0	.2	.0	12.2	
SE	.4	.4	.1	.0	.0	.0	.0	.9		.3	.0	.1	.0	19.5	
S	.2	.2	.1	.0	.0	.0	.0	.5		.7	.0	.1	.0	19.3	
SW	.1	.1	*	.0	.0	.0	.0	.3		.4	*	.1	.0	11.6	
W	*	.1	*	.0	.0	.0	.0	.1		.3	*	.4	.0	10.8	
NW	.1	.1	.0	.0	.0	.0	.0	.2		.3	.0	.2	.0	5.6	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	*	.0	.0	.0	.0	*		.2	.0	.2	.0	6.8	
TOT OBS	36	34	14	0	0	0	0		81	83	4	45	0	2612	2819
TOT PCT	1.3	1.2	.5	.0	.0	.0	.0	2.9		2.9	.1	1.6	.0	92.7	

AUGUST WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.2	.1	.1	.0	.0	.0	.0	.3		.1	*	.2	.0	4.9	
NE	.2	.1	.1	.0	.0	.0	.0	.3		.2	.0	.2	.0	6.9	
E	.5	.2	.1	.0	.0	.0	.0	.7		.5	.1	.2	.0	16.2	
SE	.3	.2	*	.0	.0	.0	.0	.5		.5	.0	.2	.0	18.0	
S	.2	.3	*	.0	.0	.0	.0	.5		.3	.0	.1	.0	16.5	
SW	.2	.2	.0	.0	.0	.0	.0	.4		.3	.0	.1	.0	10.5	
W	.2	.1	.1	.0	.0	.0	.0	.4		.2	.0	.1	.0	9.1	
NW	.1	.1	*	.0	.0	.0	.0	.3		.1	.0	.3	.0	5.3	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.1	.0	.4	.0	5.5	
TOT OBS	52	34	14	0	0	0	0		97	59	3	44	0	2584	2778
TOT PCT	1.9	1.2	.5	.0	.0	.0	.0	3.5		2.1	.1	1.6	.0	93.0	

SEPTEMBER WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	.1	.0	.0	.0	.0	.3		.1	.0	.3	*	7.8	
NE	.1	.2	.2	.0	.0	.0	.0	.5		.1	.0	.5	.0	17.8	
E	.7	.4	.4	.0	.0	.0	.0	1.3		.4	*	.5	*	26.8	
SE	.4	.3	.1	.0	.0	.0	.0	.7		.4	.1	.1	.0	17.4	
S	.2	.2	.2	.0	.0	.0	.0	.6		.1	.0	.1	.0	9.8	
SW	.1	*	*	.0	.0	.0	.0	.1		.1	.0	*	.0	3.5	
W	.1	.0	.1	.0	.0	.0	.0	.2		.1	*	.1	.0	3.6	
NW	.0	*	*	.0	.0	.0	.0	.1		*	*	.1	.0	3.0	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	*	.0	.0	.0	.0	*		.1	.0	.1	.0	2.9	
TOT OBS	47	33	30	0	0	0	0		104	39	4	49	2	2492	2690
TOT PCT	1.7	1.2	1.1	.0	.0	.0	.0	3.9		1.4	.1	1.8	.1	92.6	

OCTOBER WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	*	.0	.0	.0	.0	.2		.1	.1	1.1	.0	14.9	
NE	.3	*	.3	.0	.0	.0	.0	.6		*	.2	1.2	*	23.8	
E	.4	.3	.3	.0	.0	.0	.0	1.0		.1	.0	.4	*	24.1	
SE	.2	.4	.2	.0	.0	.0	.0	.9		.2	.0	.4	.0	11.8	
S	.1	.0	*	.0	.0	.0	.0	.1		.1	.0	.1	.0	5.3	
SW	*	.0	.0	.0	.0	.0	.0	*		*	.0	.0	.0	2.7	
W	.1	.0	*	.0	.0	.0	.0	.2		.1	.0	.1	.0	2.4	
NW	.1	*	.0	.0	.0	.0	.0	.1		.1	*	.3	.0	5.5	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		*	.0	.3	.0	1.7	
TOT OBS	33	23	22	0	0	0	0		78	21	6	100	2	2381	2584
TOT PCT	1.3	.9	.9	.0	.0	.0	.0	3.0		.8	.2	3.9	.1	92.1	

NOVEMBER WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.6	.2	.3	.0	.0	.0	*	1.0		*	.1	.6	.0	17.2	
NE	.2	.1	.4	.0	.0	.0	.0	.6		.0	.0	.7	*	16.1	
E	.2	.1	.3	.0	.0	.0	.0	.6		.1	.0	.3	.0	17.6	
SE	.1	.2	.1	.0	.0	.0	.0	.4		.1	*	.5	.0	14.4	
S	.1	.0	.1	.0	.0	.0	.0	.2		.1	*	.3	.0	10.1	
SW	.1	.1	.0	.0	.0	.0	.0	.2		.1	.0	.1	.0	4.2	
W	.1	*	*	.0	.0	.0	.0	.2		.0	.0	.1	.0	3.7	
NW	.2	.1	.1	.0	.0	.0	*	.3		*	*	.2	.0	7.8	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		*	.0	.1	.0	1.9	
TOT OBS	35	18	29	0	0	0	1		78	11	6	65	1	2101	2262
TOT PCT	1.5	.8	1.3	.0	.0	.0	*	3.4		.5	.3	2.9	*	92.9	

DECEMBER WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	.2	.0	.0	.0	.0	.3		*	.3	.5	.0	15.5	
NE	.4	.1	.4	.0	.0	.0	.0	.9		*	.3	.7	.0	14.8	
E	.4	.1	.3	.0	.0	.0	.0	.7		*	.3	.6	*	16.5	
SE	.2	.1	.2	.0	.0	.0	.0	.5		.3	.3	.6	*	14.0	
S	.3	.2	.2	.0	.0	.0	.0	.6		.1	.1	.4	.0	12.2	
SW	.2	*	.1	.0	.0	.0	.0	.2		.1	.0	.2	.0	4.4	
W	*	.1	*	.0	.0	.0	.0	.1		.0	.1	.3	.0	4.2	
NW	.1	*	.1	.0	.0	.0	.0	.2		.0	.2	*	.0	8.2	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.1	*	.0	.8	
TOT OBS	38	16	32	0	0	0	0		83	13	40	78	2	2096	2312
TOT PCT	1.6	.7	1.4	.0	.0	.0	.0	3.6		.6	1.7	3.4	.1	90.7	

TABLE F-4. (continued)

AREA: Bayou Lafourche　　　　CENTRAL POSITION: 28° 49'N 90° 04'W

PERCENTAGE FREQUENCY OF WIND DIRECTION BY SPEED AND BY HOUR

WND DIR	WIND SPEED (KNOTS) 0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	.6	3.9	4.9	1.5	.1	.0		11.0	12.6	10.0	10.6	10.5	10.7	11.3	12.1	12.0	9.7
NE	.5	5.5	6.3	1.2	.1	*		13.7	12.2	13.9	15.7	11.6	15.1	13.5	16.9	15.1	14.9
E	.9	8.6	8.2	.9	.1	*		18.6	11.6	20.4	19.9	19.8	13.5	16.3	14.7	18.6	18.4
SE	1.0	9.7	8.5	.6	.1	.0		19.9	11.3	19.7	18.4	21.9	19.7	20.4	20.1	17.9	20.0
S	1.1	7.4	5.3	.6	.1	*		14.4	11.0	13.5	11.5	14.5	13.6	16.4	12.3	14.0	13.5
SW	.5	3.7	2.0	.2	*	*		6.4	10.2	5.9	5.8	6.2	8.7	7.0	6.6	6.2	6.2
W	.4	3.1	1.8	.4	.1	*		5.8	11.2	6.4	5.6	5.2	6.8	5.9	4.8	5.7	5.8
NW	.4	2.7	2.8	.9	.1	.0		6.9	12.8	6.9	8.0	6.2	6.7	6.4	7.9	7.9	7.7
VAR	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	3.3							3.3	.0	3.3	4.5	4.0	5.1	2.9	4.7	2.5	3.7
TOT OBS	3000	15081	13045	2011	194	11	33342		11.5	6608	499	8385	586	6914	758	8993	599
TOT PCT	8.7	44.7	39.7	6.3	.6	*		100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PERCENTAGE FREQUENCY OF WEATHER OCCURRENCE BY WIND DIRECTION

WND DIR	PRECIPITATION TYPE RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	OTHER WEATHER PHENOMENA THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.2	.1	.1	.0	*	.0	*	.4		.1	.1	.4		*	9.9	
NE	.3	.1	.2	.0	.0	.0	.0	.5		.1	.2	.5		*	12.2	
E	.4	.2	.2	.0	.0	.0	.0	.7		.2	.2	.6		*	17.1	
SE	.3	.2	.2	.0	.0	.0	.0	.6		.2	.3	1.1		*	17.8	
S	.2	.1	.1	.0	.0	.0	*	.4		.2	.2	.9		*	13.0	
SW	.1	.1	*	.0	.0	.0	*	.2		.1	.1	.3		*	5.7	
W	.1	*	.1	.0	.0	.0	*	.2		.1	.1	.2		*	5.3	
NW	.1	.1	*	.0	.0	.0	*	.2		.1	.1	.3		*	6.2	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	*	.0	*	.0	.0	.0	.0	*		*	.1	.2		.0	2.7	
TOT OBS	468	234	277	0	1	0	3		940	361	361	1300		26	26919	29869
TOT PCT	1.6	.8	1.0	.0	*	.0	*	3.2		1.2	1.3	4.5		.1	89.9	

PCT FREQ OF TOTAL CLOUD AMOUNT (EIGHTHS)
BY WIND DIRECTION

WND DIR	0-2	3-4	5-7	8 & OBSCD	TOTAL OBS	MEAN CLOUD COVER
N	4.4	1.6	2.5	2.6		3.9
NE	4.9	2.3	3.1	3.1		4.0
E	6.6	4.1	5.0	3.3		4.1
SE	7.0	4.6	5.5	2.9		4.0
S	5.1	3.2	4.1	2.1		4.0
SW	2.3	1.5	1.7	.8		3.8
W	2.4	1.2	1.5	.8		3.4
NW	2.9	1.2	1.5	1.3		3.6
VAR	.0	.0	.0	.0		.0
CALM	1.8	.7	.5	.2		2.6
TOT OBS	10120	5602	6893	4436	27051	3.9
TOT PCT	37.4	20.2	25.4	17.0	100.0	

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	PCT	TOT OBS
<1	4.3	7.0	.5	.0	.0	.0	11.8	
1-2	1.1	19.2	8.6	.0	.0	.0	28.9	
3-4	.2	10.9	19.1	.7	.0	.0	31.0	
5-6	.1	1.8	12.3	1.8	*	.0	15.9	
7	.0	.2	4.9	1.9	.1	.0	7.2	
8-9	.0	.1	1.6	1.0	*	.0	2.8	
10-11	.0	.0	.4	.8	.1	.0	1.3	
12	.0	.0	.1	.3	.1	.0	.5	
13-16	.0	*	.1	.3	.1	*	.6	
17-19	.0	.0	.0	*	*	.0	*	
20-22	.0	.0	.0	.0	*	.0	*	
23-25	.0	.0	.0	.0	.0	.0	.0	
26-32	.0	.0	.0	.0	.0	.0	.0	
33-40	.0	.0	.0	.0	.0	.0	.0	
41-48	.0	.0	.0	.0	.0	.0	.0	
49-60	.0	.0	.0	.0	.0	.0	.0	
61-70	.0	.0	.0	.0	.0	.0	.0	
71-86	.0	.0	.0	.0	.0	.0	.0	
87+	.0	.0	.0	.0	.0	.0	.0	
TOT PCT	5.7	39.3	47.5	6.9	.6	*	100.0	4966

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	9.4	21.9	19.8	6.1	1.5	.5	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	16061	2
6-7	.4	2.3	6.6	6.8	2.9	1.1	.3	.2	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	5467	5
8-9	.1	.5	.9	1.5	1.4	.8	.3	.1	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	1513	6
10-11	.0	.4	.3	.3	.3	.3	.2	.1	.1	*	*	*	*	.0	.0	.0	.0	.0	.0	536	6
12-13	.0	.0	.2	.1	.1	.1	*	.1	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	156	7
>13	.0	.0	.0	*	*	*	*	*	*	*	*	.0	.0	.0	.0	.0	.0	.0	.0	66	10
INDET	5.9	1.8	1.7	1.0	.4	.3	.1	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	3097	2
TOTAL	4379	7313	7897	4180	1712	797	293	156	136	15	10	6	2	0	0	0	0	0	0	26896	3
PCT	15.7	26.8	29.6	15.9	6.6	3.1	1.1	.6	.5	.1	*	*	*	.0	.0	.0	.0	.0	.0	100.0	

Source: Same as Table F-1

TABLE F-5. ANNUAL SUMMARIES OF MARINE WEATHER OBSERVATIONS.

from the north called "northers." Temperatures during winter seldom go below freezing. Spring is mild with strong winds and frequent rain showers.

General air circulation in the SEADOCK area is under the influence of the Bermuda High during the spring and summer. In autumn and winter, the high pressure systems over the North American Continent predominate. The lowest pressures occur when the desert low to the west combines with a northerly movement of the equatorial trough. This trough moves south in winter under the influence of the intensification of the continental high pressure to the north.

Extra tropical cyclones and polar air masses moving across the North American continent during the winter frequently cause strong northerly winds and adverse weather in the SEADOCK area. These "northers" blow between November and March. Winds associated with these storms frequently reach 40 knots. Winds of over 40 knots have been observed in this area in every month of the year; however, there is an increase in their frequency during the winter.

Tropical cyclones are common to the Gulf of Mexico and a few have occurred in the SEADOCK area at infrequent intervals. These storms usually come into the area from the south or southeast. Hurricane force winds can cause tides from 10 to 25 feet above normal along the coast. The most dangerous conditions result where storm-driven waters combine with high tides along the coast. In 1900, over 6,000 persons were drowned in the Galveston area when this condition occurred. From 1899 to 1971 there was an average of one hurricane in the SEADOCK area every 3.2 years, and one tropical cyclone every 2.1 years.

As previously discussed, the wind circulation in the SEADOCK area is determined by the Bermuda High for a large part of the year. From January through June, there is a prevailing southeasterly wind which shifts to the south during July and August, then to the east until December, at which time northerly winds prevail. The frequency of "northers" is greatest during December as is the highest average monthly wind speed for the year. It is during December also that winds over 40 knots occur most frequently. It has been estimated that, on the average, there will be a maximum sustained wind speed of 95 knots in the SEADOCK area once every 25 years.[1]

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1. U.S. National Oceanic and Atmospheric Administration, Environmental Guide for the U.S. Gulf Coast (Asheville, North Carolina: National Climatic Center, 1972), p. 40.

Wave heights in this area are a function of the wind; wave heights greater than 11 feet have been observed in every month of the year. Wave heights of 20 feet or greater have been observed from September to April and in June. During hurricane "Audrey" in June 1957, waves of over 28 feet were observed in the area. It has been estimated that, on the average, a maximum wave height will occur in the area every 10 years.[1]

Coastal fog occurs year around in the area with the greatest occurrence from November through May. This time is also the period of poorest visibility in general.

Temperatures in the area of SEADOCK are moderated by the prevailing winds off the Gulf producing mild winters and pleasant summer nights. The annual average temperature is about 73°F with a minimum of 60°F in February and a maximum of 84°F in July and August.

The greatest precipitation occurs during the winter when slow, steady rains are brought on by frontal activity. The mean monthly rainfall, however, is evenly distributed throughout the year. Summer has the greatest amount of rainfall, while spring has the least. Most of the rain during the summer is from thunderstorms and, on occasion, a tropical cyclone.

There is relatively little seasonal variation in humidity in the SEADOCK area which is high all during the year due to the prevailing southeasterly winds. The maximum humidity occurs in the spring while the minimum is in the autumn.

Tables F-6 through F-12 give environmental data based on marine observations in the Galveston-Freeport area (28°30'N, 95°01'W). This information is supplemented by land station climatological data summaries for Victoria, Galveston, and Port Arthur, all of which are in the general area of SEADOCK.

d. Hurricanes

A tropical cyclone is a low pressure system which is generated over tropical ocean areas, characterized by a counterclockwise circulation of winds in the Northern Hemisphere and clockwise in the Southern Hemisphere. Tropical cyclones occur in six distinct regions of the world, one of which is the area encompassed by the North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. Figure F-1 shows the regions of tropical cyclogenesis in the Atlantic Ocean area. Although not

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1. Environmental Guide for the U.S. Gulf Coast, Op. Cit., p. 41.

STATION: VICTORIA, TEXAS
POSITION: 28° 51'N 96° 55'W
ELEVATION: 104 FEET

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Temperature – Normal – Daily minimum	Temperature – Normal – Monthly	Temperature – Extremes Ø – Record highest	Year	Temperature – Extremes Ø – Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation Ø – Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	11		11		(b)	(b)	11		11		11	
J	64.8	46.0	55.4	88	1971	16	1962	344	2.34	3.71	1966	0.02	1971	1.58	1970
F	67.4	48.6	58.0	90	1962	22	1971	230	2.34	5.42	1969	0.31	1962	2.63	1969
M	72.8	53.6	63.2	95	1971	28	1965	152	2.32	4.44	1970	0.18	1971	2.18	1970
A	78.8	61.2	70.0	98	1963	36	1971	21	2.62	9.43	1969	0.50	1964	8.57	1969
M	84.6	67.8	76.2	101	1964	49	1970	0	4.12	14.08	1968	1.00	1971	5.47	1968
J	89.3	73.2	81.3	99	1964	59	1970	0	3.04	10.67	1968	T	1967	3.10	1968
J	91.7	74.6	83.2	104	1964	62	1967	0	3.61	6.82	1961	0.27	1971	3.98	1966
A	92.3	74.4	83.4	107	1962	63	1967	0	3.13	6.84	1964	0.34	1965	6.14	1964
S	87.6	70.6	79.1	99	1965	51	1967	0	4.23	14.52	1967	1.23	1963	8.51	1967
O	82.8	62.4	72.6	95	1962	38	1964	6	3.48	6.87	1971	0.34	1964	4.34	1971
N	72.5	52.2	62.4	92	1963	27	1970	150	2.36	4.88	1961	0.10	1970	2.05	1969
D	66.9	47.5	57.2	88	1964	23	1963	270	2.61	4.91	1965	0.54	1961	2.02	1969
YR	79.3	61.0	70.2	107	AUG. 1962	16	JAN. 1962	1173	36.20	14.52	SEP. 1967	T	JUN. 1967	8.57	APR. 1969

Month	Snow, Ice pellets – Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity – Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind & – Mean speed	Prevailing direction	Peak gust – Speed	Direction	Year
(a)	10	11		11		7	10	10	10	10		9	9	
J	T	T	1968+	T	1968+	84	85	64	67	10.7		55	-	1963
F	T	T	1965+	T	1965+	81	85	59	61	11.4		51	NNW	1967+
M	0.0	0.0		0.0		82	86	57	59	11.8		59	N	1970
A	0.0	0.0		0.0		85	89	60	66	12.3		60	E	1969
M	0.0	0.0		0.0		86	90	60	65	11.3		61	ESE	1968
J	0.0	0.0		0.0		88	92	58	64	10.0		62	S	1971
J	0.0	0.0		0.0		85	91	55	58	9.2		99	-	1963
A	0.0	0.0		0.0		84	90	54	60	8.6		67	-	1963
S	0.0	0.0		0.0		86	91	61	66	8.7		53	S	1969
O	0.0	0.0		0.0		85	89	55	64	8.7		54	NNW	1967
N	0.0	0.0		0.0		84	86	56	65	9.6		48	N	1966
D	T	T	1969+	T	1969+	83	86	63	70	10.4		49	N	1968
YR	T	T	DEC. 1969+	T	DEC. 1969+	85	88	59	64	10.2		99	-	JUL. 1963

Month	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms %	Heavy fog %	Temperatures – Max. – 90 and above ‡	Max. – 32 and below	Min. – 32 and below	Min. – 0 and below	Average daily solar radiation - langleys
(a)		10	10	10	10	10	10	10	10	10	10	10	10	
J		6.9	7	7	17	6	0	1	7	0	*	6	0	
F		6.5	8	5	15	7	0	2	5	*	0	2	0	
M		6.7	6	9	16	7	0	2	5	*	0	1	0	
A		7.5	4	8	18	5	0	3	4	1	0	0	0	
M		6.8	4	11	16	7	0	6	2	6	0	0	0	
J		6.0	4	17	9	7	0	6	*	20	0	0	0	
J		5.6	6	16	9	6	0	5	*	28	0	0	0	
A		5.7	7	16	8	8	0	8	*	28	0	0	0	
S		5.9	7	13	10	11	0	8	1	16	0	0	0	
O		4.8	12	10	9	5	0	3	3	4	0	0	0	
N		5.6	10	8	12	5	0	1	6	*	0	1	0	
D		7.0	7	5	19	8	0	1	7	0	0	3	0	
YR		6.2	82	125	158	82	0	44	40	103	*	12	0	

Ø Extremes for the period June 1961 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 110 in July 1939; lowest temperature 9 in January 1930; minimum monthly precipitation 0.00 in November 1945 and earlier. Maximum monthly snowfall 5.0 in January 1940.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

% The station did not operate 24 hours daily during a part of its history. Fog and thunderstorm data may be incomplete.

Source: Same as Table F-1

TABLE F-6. LAND STATION CLIMATOLOGICAL DATA SUMMARY FOR VICTORIA, TEXAS.

STATION: GALVESTON, TEXAS
POSITION: 29° 18'N 94° 48'W
ELEVATION: 7 FEET

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Temperature – Normal – Daily minimum	Temperature – Normal – Monthly	Temperature – Extremes – Record highest	Year	Temperature – Extremes – Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Precipitation – Maximum monthly	Year	Precipitation – Minimum monthly	Year	Precipitation – Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	101		101		(b)	(b)	101		101		101	
J	60.5	49.3	54.9	77	1969	11	1886	350	3.46	10.39	1899	0.02	1909	5.38	1923
F	62.4	51.2	56.8	83	1932	8	1899	258	2.88	8.29	1881	0.09	1954	6.55	1952
M	66.6	56.2	61.4	85	1879	27	1943	189	2.86	9.39	1926	0.06	1953	4.58	1944
A	73.0	64.0	68.5	92	1953	38	1938	30	2.59	11.04	1904	0.01	1887	9.23	1904
M	80.1	71.5	75.8	93	1911	52	1954+	0	2.79	10.50	1929	T	1889	6.13	1916
J	85.6	77.7	81.7	99	1918	57	1903	0	2.65	15.49	1919	T	1907	12.56	1961
J	87.3	78.9	83.1	101	1932	66	1910	0	4.79	18.74	1900	T	1962+	14.35	1900
A	87.5	79.0	83.3	100	1924	67	1966+	0	4.39	19.08	1915	0.00	1902	9.05	1915
S	84.6	75.5	80.1	96	1927	52	1942	0	5.09	26.01	1885	0.04	1924	11.65	1961
O	78.5	68.4	73.5	94	1952+	41	1925+	0	2.86	17.78	1871	T	1952+	14.10	1901
N	68.6	57.4	63.0	85	1886	26	1911	138	3.56	16.18	1940	0.03	1903	9.01	1940
D	62.7	51.6	57.2	80	1918	18	1880	270	3.89	10.28	1887	0.23	1889	5.43	1964
YR	74.8	65.1	69.9	101	JUL. 1932	8	FEB. 1899	1235	41.81	26.01	SEP. 1885	0.00	AUG. 1902	14.35	JUL. 1900

Month	Snow, Ice pellets – Mean total	Snow, Ice pellets – Maximum monthly	Year	Snow, Ice pellets – Maximum in 24 hrs.	Year	Relative humidity – Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind & – Mean speed %	Wind – Prevailing direction	Wind – Fastest mile – Speed	Fastest mile – Direction #	Fastest mile – Year	Pct. of possible sunshine
(a)	101	101		101		32	84	54	84	93		100	100		81
J	T	0.9	1940	0.9	1940	84	85	77	80	11.6		53	S	1915	49
F	0.2	15.4	1895	15.4	1895	83	84	74	77	11.8		60	N	1927	50
M	T	T	1932	T	1932	84	85	74	79	11.9		50	SE	1952	56
A	0.0	0.0		0.0		86	86	75	80	12.1		57	NW	1961	61
M	0.0	0.0		0.0		83	84	73	77	11.5		66	W	1959	68
J	0.0	0.0		0.0		80	81	70	73	10.7		62	SE	1921	76
J	0.0	0.0		0.0		80	81	70	73	9.8		68	NW	1943	72
A	0.0	0.0		0.0		79	81	69	73	9.4		91	E	1915	71
S	0.0	0.0		0.0		78	81	68	75	10.1		100	NE	1900	69
O	0.0	0.0		0.0		76	80	65	71	10.3		66	SE	1949	72
N	0.0	0.0		0.0		82	84	72	77	11.2		54	N	1950	61
D	T	0.2	1924	0.2	1924	83	86	77	80	11.3		50	NW	1954	49
YR	0.2	15.4	FEB. 1895	15.4	FEB. 1895	81	83	72	76	11.0		Ø 100	NE	SEP. 1900	64

Month	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max – 90° and above ‡	Max – 32° and below	Min – 32° and below	Min – 0° and below	Average daily solar radiation - langleys
(a)					100	100			86	101	101	101	
J					10	0			0	*	2	0	
F					9	*			0	*	1	0	
M					8	0			0	0	*	0	
A					6	0			*	0	0	0	
M					6	0			*	0	0	0	
J					6	0			1	0	0	0	
J					9	0			4	0	0	0	
A					9	0			5	0	0	0	
S					9	0			1	0	0	0	
O					6	0			*	0	0	0	
N					8	0			0	0	*	0	
D					10	0			0	*	1	0	
YR					96	*			11	*	4	0	

Ø 100 m.p.h. recorded at 6:15 p.m. Sept. 8 just before anemometer blew away. Maximum velocity estimated 120 from NE between 7:30 and 8:30 p.m.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≧ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

% Through 1964.

\# To 8 compass points only.

Source: Same as Table F-1

TABLE F-7. LAND STATION CLIMATOLOGICAL DATA SUMMARY FOR GALVESTON, TEXAS.

STATION: PORT ARTHUR, TEXAS
POSITION: 29° 57'N 94° 01'W
ELEVATION: 16 FEET

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation Ø: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	11		11		(b)	(b)	18		18		18		18	18		18	
J	63.5	43.7	53.6	80	1965	14	1962	384	4.23	9.57	1961	0.60	1971	4.92	1961	T	T	1964+	T	1964+
F	65.8	46.2	56.0	84	1962	25	1968+	274	4.45	11.76	1959	0.36	1954	5.05	1965	0.4	4.4	1960	4.4	1960
M	71.3	50.8	61.1	86	1967	27	1968+	192	3.44	8.83	1957	0.06	1955	4.21	1957	0.1	1.4	1968	1.4	1968
A	78.0	58.3	68.2	90	1965	37	1971+	39	3.94	7.38	1968	0.35	1965	7.23	1968	0.0	0.0		0.0	
M	83.8	65.6	74.7	92	1963+	47	1970	0	4.94	9.63	1966	0.55	1960	7.18	1954	0.0	0.0		0.0	
J	89.6	71.5	80.6	99	1963	60	1970+	0	4.29	14.05	1961	0.96	1970	10.20	1961	0.0	0.0		0.0	
J	91.0	72.7	81.9	103	1970	61	1967	0	6.00	18.71	1959	0.63	1956	4.87	1964	0.0	0.0		0.0	
A	91.2	73.3	82.3	107	1962	62	1967	0	5.49	17.26	1966	0.98	1968	8.45	1966	0.0	0.0		0.0	
S	88.4	68.0	78.2	99	1963	45	1967	0	4.88	18.15	1963	0.50	1953	13.17	1963	0.0	0.0		0.0	
O	81.7	58.8	70.3	95	1963	37	1964	22	2.88	15.09	1970	0.00	1963	8.06	1970	0.0	0.0		0.0	
N	70.7	48.6	59.7	87	1963	27	1969	207	3.46	10.42	1961	0.15	1967	7.26	1961	0.0	0.0		0.0	
D	64.9	44.6	54.8	82	1970	17	1963	329	5.09	12.47	1956	1.32	1954	6.24	1956	T	T	1953	T	1953
YR	78.3	58.5	68.5	107	AUG. 1962	14	JAN. 1962	1447	53.09	18.71	JUL. 1959	0.00	OCT. 1963	13.17	SEP. 1963	0.5	4.4	FEB. 1960	4.4	FEB. 1960

Month	Relative humidity: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Max.: 90° and above ‡	Max.: 32° and below	Min.: 32° and below	Min.: 0° and below	Average daily solar radiation - langleys
(a)	11	11	11	11	18	10	18	18		18	18	18	18	18	16	18	18	18	11	11	11	11	
J	87	89	69	77	11.4	N	50	S	1957	42	7.0	6	7	18	9	0	2	8	0	*	7	0	
F	85	88	62	71	12.1	S	62	SE	1969	51	6.3	8	6	14	9	*	3	6	0	0	4	0	
M	87	89	61	69	12.2	S	66	SW	1964	53	6.4	7	9	15	8	*	2	6	0	0	2	0	
A	89	92	65	73	12.4	S	60	NW	1966+	52	6.8	6	8	16	7	0	4	3	*	0	0	0	
M	89	91	63	71	10.8	S	74	SW	1971	64	6.1	6	13	12	7	0	6	1	2	0	0	0	
J	90	93	62	69	9.0	S	72	NW	1957	69	5.4	8	15	7	7	0	7	*	19	0	0	0	
J	92	93	63	70	8.1	S	66	SW	1963	67	6.0	5	17	9	11	0	13	*	26	0	0	0	
A	90	93	64	72	7.6	S	73	E	1964	65	5.8	7	15	9	12	0	11	*	24	0	0	0	
S	89	91	63	73	8.8	NE	56	SW	1968	63	5.5	9	11	10	10	0	7	1	14	0	0	0	
O	87	89	56	71	9.1	N	65	NW	1956	67	4.7	12	11	8	6	0	3	3	2	0	0	0	
N	86	88	58	74	10.5	N	60	NE	1963	58	5.6	10	8	12	7	0	2	5	0	0	1	0	
D	87	90	68	79	10.9	N	69	S	1953	46	6.4	8	7	16	10	0	2	7	0	*	4	0	
YR	88	90	63	73	10.2	S	74	SW	MAY 1971	59	6.0	92	127	146	103	*	62	42	87	*	17	0	

Ø Record for partial year, June-December 1953, considered in extracting precipitation extremes.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Lowest temperature 11 in January 1930; maximum monthly precipitation 24.25 inches in July 1943; maximum precipitation in 24 hours 17.76 in July 1943;
fastest mile of wind 91 from Northeast in August 1940.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

Source: Same as Table F-1

TABLE F-8. LAND STATION CLIMATOLOGICAL DATA SUMMARY FOR PORT ARTHUR, TEXAS.

ENVIRONMENTAL DATA SUMMARY (PART 1)

AREA: Galveston - Freeport

CENTRAL POSITION: 28° 30'N 95° 01'W

ENVIRONMENTAL FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
WIND SPEED (KNOTS)													
01% ≤	0	0	0	0	0	0	0	0	0	0	0	0	0
05% ≤	1	1	1	2	1	1	1	1	1	1	2	2	1
25% ≤	6	6	6	6	5	5	4	4	5	6	6	6	5
50% ≤	12	10	10	11	9	8	7	7	9	10	11	11	9
75% ≤	17	17	16	16	15	14	11	11	15	16	17	18	16
95% ≤	28	27	25	23	21	20	19	19	22	25	28	29	24
99% ≤	33	30	30	30	28	25	21	22	35	30	30	32	29
Maximum observed	Winds in excess of 115 knots are estimated to have occurred during great hurricanes. Winds of 150 knots are considered possible in an intense hurricane for this area.												
Mean	12.2	12.0	11.8	11.7	10.8	9.8	8.7	8.5	11.0	11.9	12.8	12.9	11.1
≥ 34 Knots (% freq.)	1.0	0.7	0.3	0.4	0.2	0.2	+	0.1	1.0	0.7	0.7	0.8	0.5
≥ 41 Knots (% freq.)	0.3	0.2	0.1	0.1	0.1	0.1	+	0.1	0.4	0.2	0.2	0.4	0.2
Prevailing direction	SE	SE	SE	SE	SE	SE	S	S	E	E	E	N	SE
SEA-LEVEL PRESSURE (mb)													
Minimum observed	999	994	997	992	1001	980	1000	1000	987	1001	1000	1002	980
01% ≤	1004	1003	1001	1003	1006	1007	1010	1009	1004	1007	1006	1006	1006
05% ≤	1010	1008	1006	1008	1009	1010	1012	1012	1010	1010	1011	1011	1010
25% ≤	1017	1015	1013	1013	1013	1013	1015	1014	1013	1014	1015	1017	1014
50% ≤	1021	1019	1017	1017	1016	1015	1017	1016	1015	1017	1019	1020	1017
75% ≤	1025	1022	1021	1020	1018	1017	1019	1018	1017	1020	1023	1024	1020
95% ≤	1030	1028	1027	1024	1022	1019	1021	1020	1020	1024	1028	1030	1024
99% ≤	1035	1034	1031	1028	1025	1021	1023	1022	1022	1027	1033	1034	1028
Maximum observed	1040	1041	1035	1031	1031	1027	1025	1027	1030	1037	1036	1040	1041
Mean	1021	1019	1017	1016	1016	1015	1017	1016	1015	1017	1019	1020	1017
WEATHER & CLOUDS (% FREQ.)													
Precipitation	3.3	4.2	2.1	2.1	1.8	1.8	2.2	2.2	2.8	2.4	2.8	4.9	2.7
Freezing precipitation	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+
Frozen precipitation	0.1	0.1	0.0	0.0	+	0.0	0.0	0.0	0.0	+	0.0	0.0	+
Thunder & lightning	0.4	1.1	0.5	0.6	1.0	1.4	0.9	1.8	1.7	1.0	1.2	1.0	1.0
Sky ≤2/8	33.7	33.4	33.7	36.1	38.7	41.0	36.1	34.1	34.1	44.3	40.2	35.4	36.7
Low cloud overcast	20.7	21.0	17.4	11.2	5.9	3.1	2.3	3.7	6.1	6.5	12.2	18.8	10.7
Total sky overcast	31.3	29.5	27.0	21.9	13.2	7.9	8.3	9.2	13.6	13.9	19.8	29.4	18.7
Sky obscured	2.2	2.5	2.5	2.0	0.1	0.3	0.1	0.1	0.3	0.1	0.8	1.7	1.1
Mean cloud cover (eighths)	4.6	4.6	4.5	4.2	3.7	3.4	3.6	3.8	3.9	3.4	3.9	4.4	4.0
VISIBILITY (% FREQ.)													
Visibility <½ N. mile	1.5	1.8	1.8	1.1	0.1	0.1	0.1	0.1	0.3	+	0.5	1.2	0.7
Visibility <1 N. mile	2.0	2.1	2.3	1.4	0.3	0.3	0.2	0.2	0.3	+	0.6	1.6	0.9
Visibility <2 N. mile	2.6	3.2	3.0	2.3	0.7	0.4	0.2	0.4	0.3	0.1	0.8	2.6	1.3
Visibility <5 N. mile	5.5	6.7	7.5	7.3	2.5	2.0	0.6	0.7	1.2	0.6	2.9	5.0	3.4
Visibility <10 N. mile	27.0	28.8	29.0	33.6	21.9	9.5	6.3	7.6	11.4	12.9	18.5	25.6	19.3
FOG													
Occurrence of fog (% freq.)	6.4	5.9	5.9	4.9	0.7	0.1	0.3	0.2	0.2	0.4	2.7	3.5	2.6
Mean number of hours operation of fog signals*	105	72	86	37	3	3	2	4	4	8	27	78	429
Maximum numbers of hours operation of fog signals for any year (annual only)*													697

+ = Less than 0.05%. * Galveston Jetty fog signal. Source: Same as Table F-1

TABLE F-9. ENVIRONMENTAL DATA SUMMARY; GALVESTON-FREEPORT AREA.

ENVIRONMENTAL DATA SUMMARY (PART 2)

AREA: Galveston - Freeport

CENTRAL POSITION: 28° 30'N 95° 01'W

ENVIRONMENTAL FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
WAVES (FEET)													
01% ≤	1	1	1	1	1	1	1	1	1	1	1	1	1
05% ≤	1	1	1	1	1	1	1	1	1	1	1	1	1
25% ≤	2	2	2	2	1	1	1	1	1	1	2	2	1
50% ≤	4	4	3	3	3	2	2	2	3	3	4	4	3
75% ≤	6	6	5	5	5	4	3	3	5	5	5	6	5
95% ≤	9	9	8	7	7	7	6	6	7	7	9	9	8
99% ≤	12	12	12	12	10	10	5	7	10	12	12	12	10
Maximum observed	25	21	25	21	15	28	13	16	20	21	23	25	28
Mean	4	4	4	3	3	3	2	2	3	3	4	4	3
≥ 5 Feet (% freq.)	37.1	35.2	32.7	32.1	25.6	18.7	11.8	12.7	26.5	29.0	37.4	35.8	28.0
≥ 8 Feet (% freq.)	8.0	9.3	7.0	4.8	4.0	3.0	1.1	0.8	4.6	5.0	8.8	8.2	5.5
≥ 12 Feet (% freq.)	1.9	2.7	1.7	1.1	0.7	0.7	0.2	0.2	0.9	1.2	1.9	2.2	1.4
≥ 20 Feet (% freq.)	0.1	0.1	0.2	0.2	0.0	0.2	0.0	0.0	+	0.4	0.2	+	0.2
RELATIVE HUMIDITY (%)													
Mean	81	80	81	83	82	79	77	77	77	74	77	78	79
AIR TEMPERATURE (°F)													
Minimum observed	29	33	41	51	59	70	72	73	62	54	37	32	29
01% ≤	40	42	46	56	65	74	77	76	71	60	48	41	58
05% ≤	45	48	52	61	70	77	80	79	75	66	54	48	63
25% ≤	52	54	58	65	73	79	82	81	78	71	61	55	67
50% ≤	61	62	65	70	77	82	84	84	82	77	70	64	73
75% ≤	67	68	69	74	80	85	87	87	85	81	74	70	77
95% ≤	72	72	73	77	83	88	89	89	88	84	78	74	81
99% ≤	76	76	78	82	86	92	94	93	92	88	82	78	85
Maximum observed	80	85	88	87	92	99	100	100	100	97	91	90	100
Mean	59.9	61.5	64.4	70.0	76.4	81.9	84.1	84.1	81.9	75.9	68.4	62.8	73.1
≥ 32 °F (% freq.)	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	+
≥ 85 °F (% freq.)	0.0	0.1	0.1	0.3	2.2	18.5	41.1	42.4	20.0	4.7	0.4	0.2	10.9
SEA TEMPERATURE (°F)													
Minimum observed	48	44	50	58	64	67	73	74	70	60	50	49	44
01% ≤	50	51	54	62	70	75	79	80	77	70	60	53	54
05% ≤	54	54	57	64	71	77	81	82	80	73	64	57	59
25% ≤	60	59	62	67	74	81	83	84	82	77	69	63	67
50% ≤	63	63	65	69	76	82	85	85	84	79	73	67	76
75% ≤	67	67	68	72	79	84	86	87	85	82	76	71	83
95% ≤	72	70	72	76	82	86	88	88	88	84	79	75	87
99% ≤	76	76	75	79	84	88	90	90	89	86	82	78	89
Maximum observed	82	79	83	84	91	92	94	93	91	89	86	84	94
Mean	63.5	63.2	64.9	69.7	76.5	82.4	84.9	85.4	83.8	79.3	72.3	66.7	74.3
SALINITY (‰)													
Minimum observed	30.1	31.3	32.4	31.4	31.1	31.8	32.0	32.8	32.1	32.4	33.0	32.5	30.1
Mean	34.1	34.8	35.2	34.5	33.0	33.5	34.2	35.0	34.4	34.3	36.2	35.0	34.5
Maximum observed	36.6	36.5	36.4	36.5	34.9	35.4	36.1	36.5	36.2	36.0	36.6	36.4	36.6
DENSITY (ρ)													
Mean (σ_t)*	25.0	25.5	25.3	25.2	21.8	24.8	25.1	25.3	22.7	22.6	24.6	25.3	24.4

+ = Less than 0.05%. * $\sigma_t = (\rho - 1) \times 10^3; \rho = \text{gm cm}^{-3}$.

TABLE F-9. (continued)

AREA: Galveston - Freeport

CENTRAL POSITION: 28° 30'N 95° 01'W

JANUARY

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.5	4.4	8.3	3.7	.4	.1		17.5	16.4
NE	.6	5.2	6.2	1.6	.1	.0		13.8	13.5
E	1.4	6.8	7.7	.8	.1	.0		16.7	11.7
SE	1.1	8.2	7.9	.5	.0	.0		17.7	10.6
S	1.7	6.8	4.9	.5	.0	.0		13.9	10.1
SW	.8	3.0	1.3	.2	.0	.0		5.3	9.0
W	.3	1.6	1.5	.3	*	.0		3.7	12.3
NW	.5	3.4	3.6	1.3	.2	*		9.1	14.1
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.3							2.3	.0
TOT OBS	183	786	823	178	17	2	1989		12.2
TOT PCT	9.2	39.5	41.4	8.9	.9	.1		100.0	

FEBRUARY

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.5	4.8	6.9	2.1	.3	.0		14.7	14.8
NE	.8	5.3	6.3	2.2	.1	.0		14.7	13.8
E	1.2	5.7	7.5	1.5	.1	.1		16.0	12.8
SE	1.6	9.0	7.7	.4	*	.0		18.6	10.4
S	1.7	8.0	5.3	.6	*	.0		15.6	10.3
SW	.5	3.2	1.0	.1	.0	.0		4.9	8.7
W	.7	2.4	1.2	.2	.0	.0		4.5	9.9
NW	.4	2.4	3.8	1.7	.1	.0		8.4	15.4
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.5							2.5	.0
TOT OBS	176	731	711	161	11	1	1791		12.0
TOT PCT	9.8	40.8	39.7	9.0	.6	.1		100.0	

MARCH

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	1.0	4.6	6.2	2.4	.1	.0		14.3	14.2
NE	.8	5.1	5.6	1.3	*	.0		12.8	12.5
E	.8	7.8	7.1	.7	*	.0		16.5	11.6
SE	1.2	12.8	10.3	.5	.0	.0		24.9	10.9
S	.9	7.5	6.6	.5	.0	.0		15.5	10.9
SW	.4	2.3	1.0	.0	.0	.0		3.7	8.9
W	.3	1.2	1.6	.1	.0	.0		3.2	11.8
NW	.2	2.4	2.7	1.3	.1	.0		6.7	15.3
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.5							2.5	.0
TOT OBS	165	884	831	140	7	0	2027		11.6
TOT PCT	8.1	43.6	41.0	6.9	.3	.0		100.0	

APRIL

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.4	3.1	4.7	1.5	.1	.0		9.8	14.4
NE	1.1	3.9	4.5	.8	.0	.0		10.2	12.0
E	1.1	8.9	6.9	.7	.0	.0		17.6	10.9
SE	1.5	14.1	16.2	1.1	.1	.0		32.9	11.8
S	.9	7.6	7.4	.6	.1	.0		16.6	11.4
SW	.3	2.3	1.1	.1	.0	.0		3.8	9.4
W	.3	1.2	.9	.2	.0	.0		2.6	10.8
NW	.1	.9	2.6	.9	*	.0		4.5	15.7
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.0							2.0	.0
TOT OBS	144	779	821	108	7	0	1859		11.7
TOT PCT	7.7	41.9	44.2	5.8	.4	.0		100.0	

MAY

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.8	2.8	2.5	.6	.1	.0		6.8	11.7
NE	.4	3.7	3.6	.6	.1	.0		8.5	12.1
E	1.3	7.9	6.4	.7	*	.0		16.4	11.1
SE	1.7	14.9	17.2	1.1	*	.0		34.9	11.6
S	1.4	9.7	8.0	.6	.0	.0		19.7	10.9
SW	.5	2.8	1.1	.0	.0	.0		4.4	8.6
W	.3	1.6	.6	*	.0	.0		2.6	8.0
NW	.5	1.4	.8	.5	.0	.0		3.2	11.2
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	3.6							3.6	.0
TOT OBS	216	914	819	82	5	0	2036		10.8
TOT PCT	10.6	44.9	40.2	4.0	.2	.0		100.0	

JUNE

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.3	1.4	.6	*	.0	.0		2.4	8.4
NE	.6	3.2	1.7	.1	*	.0		5.7	9.6
E	1.5	7.6	4.3	.2	*	.0		13.7	9.5
SE	1.6	17.4	12.3	.7	*	.0		31.9	10.7
S	1.9	13.9	11.6	.6	*	.0		28.0	10.7
SW	.5	4.3	2.6	.3	*	.0		7.7	10.1
W	.6	2.3	1.2	.0	.0	*		4.1	9.3
NW	.3	1.4	.3	.0	.0	.0		2.0	7.7
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	4.5							4.5	.0
TOT OBS	256	1128	755	42	5	1	2187		9.8
TOT PCT	11.7	51.6	34.5	1.9	.2	*		100.0	

JULY

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.9	1.1	.7	.0	.0	.0		2.6	7.2
NE	.5	2.1	1.0	.0	.0	.0		3.6	8.8
E	.8	5.4	2.6	*	.0	.0		8.9	9.4
SE	2.0	15.9	6.6	.1	.0	.0		24.6	9.0
S	2.5	18.5	9.5	.5	*	.0		31.0	9.4
SW	1.0	8.9	3.7	.1	.0	.0		13.7	9.1
W	1.2	5.0	2.0	.1	.0	.0		8.3	8.5
NW	.6	1.8	.6	*	.0	.0		3.1	7.6
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	4.1							4.1	.0
TOT OBS	279	1209	551	17	1	0	2057		8.7
TOT PCT	13.6	58.8	26.8	.8	*	.0		100.0	

AUGUST

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.6	2.6	.9	.1	.0	.0		4.1	8.0
NE	.6	4.9	2.5	.2	*	.0		8.3	9.9
E	1.5	8.7	3.9	.1	*	.0		14.3	8.9
SE	2.2	14.7	6.2	.1	.0	.0		23.1	9.1
S	2.5	15.3	6.8	.5	.0	.0		25.1	9.0
SW	1.3	6.7	2.4	.1	.0	.0		10.5	8.6
W	1.0	4.8	1.1	*	.0	.0		6.9	7.7
NW	.5	1.8	.6	.1	.0	.0		3.1	8.0
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	4.6							4.6	.0
TOT OBS	314	1266	517	25	2	0	2124		8.5
TOT PCT	14.8	59.6	24.3	1.2	.1	.0		100.0	

SEPTEMBER

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	1.0	4.0	3.5	.7	.0	.0		9.2	11.8
NE	1.0	7.3	8.3	1.5	.3	.1		18.5	13.0
E	1.6	12.9	11.1	.8	.1	.1		26.6	11.4
SE	1.7	11.6	7.9	.7	.2	.1		22.1	11.1
S	1.0	6.3	4.3	.4	*	.1		12.1	10.3
SW	.3	1.8	.8	*	.0	.0		2.9	8.3
W	.1	.9	.9	*	.0	.0		1.9	10.7
NW	.3	1.8	.9	*	.0	.0		2.9	9.6
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	3.6							3.6	.0
TOT OBS	233	1026	825	93	14	9	2200		11.0
TOT PCT	10.6	46.6	37.5	4.2	.6	.4		100.0	

OCTOBER

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.9	4.8	8.0	2.1	.5	.1		16.3	15.1
NE	.7	8.8	9.3	1.4	.1	.0		20.1	12.4
E	1.6	11.4	9.9	.8	.0	.0		23.7	11.2
SE	.9	8.5	8.3	.7	.0	.0		18.4	11.4
S	.9	4.4	3.9	.4	*	.0		9.5	11.2
SW	.3	1.4	.8	.1	*	.0		2.7	9.9
W	.2	1.3	1.1	.1	.0	.0		2.7	10.2
NW	.1	1.9	1.7	.5	*	.0		4.3	13.4
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.3							2.3	.0
TOT OBS	171	915	927	131	13	2	2159		11.9
TOT PCT	7.9	42.4	42.9	6.1	.6	.1		100.0	

NOVEMBER

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	1.0	4.7	7.8	3.3	.4	.1		17.2	15.7
NE	.7	5.3	7.2	1.7	.0	.0		15.0	13.6
E	1.0	9.1	7.2	1.0	.1	.0		18.2	11.3
SE	.3	8.1	8.0	.9	.0	.0		17.3	11.9
S	.9	5.8	8.0	1.4	.0	.0		16.1	12.6
SW	.1	1.9	1.7	.4	.0	.0		4.0	12.4
W	.2	1.7	1.2	.2	.0	.0		3.4	11.6
NW	.3	2.0	3.2	1.0	.1	.0		6.6	14.8
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.1							2.1	.0
TOT OBS	129	754	863	193	11	1	1951		12.8
TOT PCT	6.6	38.6	44.2	9.9	.6	.1		100.0	

DECEMBER

WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD
	WIND SPEED (KNOTS)								
N	.6	4.5	7.8	4.5	.3	.1		17.8	16.7
NE	.6	6.2	8.7	2.1	.1	.0		17.7	13.8
E	.8	6.6	7.6	1.0	.1	.0		16.0	12.3
SE	.9	8.9	6.5	.8	.1	.0		17.2	11.1
S	1.0	5.8	5.1	.8	.0	.0		12.8	11.2
SW	.5	2.2	1.4	.2	.0	.0		4.4	10.2
W	.2	1.8	1.4	.3	.0	.0		3.8	11.5
NW	.6	2.4	3.3	1.7	.1	.1		8.3	15.7
VAR	.0	.0	.0	.0	.0	.0		.0	.0
CALM	2.0							2.0	.0
TOT OBS	133	701	760	210	11	4	1819		12.9
TOT PCT	7.3	38.5	41.8	11.5	.6	.2		100.0	

Source: Same as Table F-1

TABLE F-10. MONTHLY SUMMARIES WIND DIRECTION AND SPEED (PERCENTAGE FREQUENCY) BASED ON MARINE OBSERVATIONS.

AREA: Galveston - Freeport

CENTRAL POSITION: 28° 30'N 95° 01'W

JANUARY WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.2	.0	.4	.0	.0	.0	*	.5		.0	1.0	.7		.1	15.6	
NE	.3	.1	.3	.0	.0	.0	.0	.7		.0	.7	.3		.0	12.6	
E	.6	.2	.6	.0	.0	.0	.0	1.1		.2	1.3	1.0		.0	13.3	
SE	.2	*	.1	.0	.0	.0	.0	.4		.1	1.7	1.4		.0	14.5	
S	.1	*	.2	.0	.0	.0	.0	.3		.0	.7	1.7		.0	11.0	
SW	.1	.1	.0	.0	.0	.0	.0	.2		.1	.1	.6		.0	4.1	
W	.0	.0	.0	.0	.0	.0	.0	.0		.1	.1	.3		.0	3.3	
NW	.1	.0	.1	.0	.0	.0	*	.2		*	.3	.3		.0	7.5	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.4	.2		.0	1.4	
TOT OBS	24	6	27	0	0	0	1		55	7	105	106		1	1362	1636
TOT PCT	1.5	.4	1.7	.0	.0	.0	.1	3.4		.4	6.4	6.5		.1	83.3	

FEBRUARY WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.4	.1	.4	.1	.0	.0	.0	.8		.2	.6	.6		.3	11.9	
NE	.5	*	.3	.0	.0	.1	.0	.9		.3	.2	.7		.0	13.2	
E	.8	.0	.4	.0	.0	.0	.0	1.0		.2	.5	1.5		.0	14.0	
SE	.3	.1	.2	.0	.0	.0	.0	.5		.3	1.7	2.2		.0	14.1	
S	.2	.0	.5	.0	.0	.0	.0	.7		.1	1.5	1.5		.0	11.8	
SW	.0	.0	*	.0	.0	.0	.0	*		*	.2	.3		.0	3.5	
W	.2	.0	.0	.0	.0	.0	.0	.2		.0	.1	.3		.0	4.0	
NW	.1	.0	*	.0	.0	.0	.0	.1		.0	.6	.4		.2	6.9	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.1	.3	.3		.0	1.5	
TOT OBS	36	3	25	1	0	1	0		61	16	84	112		6	1158	1432
TOT PCT	2.5	.2	1.7	.1	.0	.1	.0	4.3		1.1	5.9	7.8		.4	80.9	

MARCH WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.4	.0	.3	.0	.0	.0	.0	.5		.1	.5	.8		.3	12.3	
NE	.2	.0	.4	.0	.0	.0	.0	.5		.1	.5	.6		.1	11.2	
E	.2	.0	.3	.0	.0	.0	.0	.5		.1	.6	1.4		*	13.9	
SE	.1	.0	.2	.0	.0	.0	.0	.3		.1	1.7	3.9		*	18.4	
S	*	.1	*	.0	.0	.0	.0	.1		.1	1.3	2.3		.1	11.7	
SW	.0	.0	.0	.0	.0	.0	.0	.0		.0	.3	.5		.1	2.6	
W	.0	.0	*	.0	.0	.0	.0	*		.0	.4	.2		.1	2.7	
NW	.0	.0	.1	.0	.0	.0	.0	.1		.1	.2	.3		.0	6.1	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.6	.3		.0	1.6	
TOT OBS	15	1	24	0	0	0	0		35	8	101	179		11	1375	1709
TOT PCT	.9	.1	1.4	.0	.0	.0	.0	2.0		.5	5.9	10.5		.6	80.5	

APRIL WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.4	.0	.3	.0	.0	.0	.0	.6		.0	.2	.5		.0	8.1	
NE	.2	.0	.0	.0	.0	.0	.0	.2		.0	.5	.4		.0	9.3	
E	.3	.0	.0	.0	.0	.0	.0	.3		.1	.9	2.4		.0	14.6	
SE	.5	.1	.0	.0	.0	.0	.0	.6		.4	1.8	7.0		.1	23.5	
S	.1	.1	.0	.0	.0	.0	.0	.2		.2	.9	2.9		.0	11.8	
SW	.1	.0	.0	.0	.0	.0	.0	.1		.0	.1	.5		.0	3.1	
W	.0	.0	.0	.0	.0	.0	.0	.0		.0	.1	.4		.0	2.2	
NW	.1	.0	.0	.0	.0	.0	.0	.1		.0	.1	.0		.0	4.0	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	.1	.0	.0	.0	.0	.0	.0	.1		.0	.2	.1		.0	1.5	
TOT OBS	26	3	4	0	0	0	0		33	10	77	224		2	1223	1567
TOT PCT	1.7	.2	.3	.0	.0	.0	.0	2.1		.6	4.9	14.3		.1	78.0	

MAY WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	.0	.0	.0	.0	.1	.2		*	.0	.4		.0	6.2	
NE	.2	.1	.1	.0	.0	.0	.0	.3		.1	.1	.4		.0	8.0	
E	.3	.2	.2	.0	.0	.0	.0	.6		.3	.1	.8		.0	13.9	
SE	.0	.1	*	.0	.0	.0	.0	.2		.3	.4	3.0		.0	30.9	
S	.2	.0	.1	.0	.0	.0	.0	.3		*	.2	1.5		.1	18.2	
SW	*	.0	.0	.0	.0	.0	.0	*		.1	.0	.2		.0	4.0	
W	.1	.1	.0	.0	.0	.0	.0	.2		.1	.0	.1		.0	2.4	
NW	.1	.0	.0	.0	.0	.0	.0	.1		.1	.0	.1		.0	2.8	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.9		.0	2.7	
TOT OBS	17	8	7	0	0	0	1		33	17	13	134		1	1571	1766
TOT PCT	1.0	.5	.4	.0	.0	.0	.1	1.9		1.0	.7	7.6		.1	89.0	

JUNE WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.0	.1	.0	.0	.0	.0	.0	.1		.0	.0	.1		.0	2.4	
NE	.1	*	.0	.0	.0	.0	.0	.1		.2	.0	.3		.0	5.1	
E	.1	.1	.1	.0	.0	.0	.0	.2		.2	.1	.6		.1	11.9	
SE	.3	.1	.1	.0	.0	.0	.0	.4		.4	.0	1.0		.0	29.8	
S	.4	.1	.0	.0	.0	.0	.0	.5		.3	.0	1.0		.0	26.6	
SW	*	.1	.1	.0	.0	.0	.0	.2		.1	.0	.1		.0	7.4	
W	*	*	.1	.0	.0	.0	.0	.1		*	.0	.2		.0	3.9	
NW	.1	*	.1	.0	.0	.0	.0	.1		.1	.0	.2		.0	1.7	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	.1	.0	.0	.0	.0	.0	.0	.1		.1	.0	.8		.0	3.7	
TOT OBS	20	8	7	0	0	0	0		35	28	2	84		1	1819	1968
TOT PCT	1.0	.4	.4	.0	.0	.0	.0	1.8		1.4	.1	4.3		.1	92.4	

Source: Same as Table F-1

TABLE F-11. MONTHLY SUMMARIES OF WEATHER OCCURRENCE BY WIND DIRECTION (PERCENTAGE FREQUENCY) BASED ON MARINE OBSERVATIONS.

AREA: Galveston - Freeport CENTRAL POSITION: 28° 30'N 95° 01'W

JULY				PRECIPITATION TYPE								OTHER WEATHER PHENOMENA			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.0	.1	.0	.0	.0	.0	.0	.1		.1	.1	.2	.0	2.3	
NE	.1	.0	.1	.0	.0	.0	.0	.2		.0	.1	.2	.0	3.1	
E	.2	.1	*	.0	.0	.0	.0	.2		.0	.0	.1	.0	8.8	
SE	.3	.2	.2	.0	.0	.0	.0	.6		.2	.0	.2	.0	23.2	
S	.4	.1	.2	.0	.0	.0	.0	.6		.2	.1	.5	.0	30.1	
SW	*	.0	*	.0	.0	.0	.0	.1		.1	.0	.2	.1	13.3	
W	.2	*	.1	.0	.0	.0	.0	.3		.1	*	.3	.0	7.8	
NW	*	.1	.0	.0	.0	.0	.0	.1		*	*	.4	.0	2.6	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.1	.0	.0	.0	.0	.1		.1	.0	.2	.0	3.6	
TOT OBS	22	9	13	0	0	0	0		39	15	4	38	1	1709	1804
TOT PCT	1.2	.5	.7	.0	.0	.0	.0	2.2		.8	.2	2.1	.1	94.7	

AUGUST				PRECIPITATION TYPE								OTHER WEATHER PHENOMENA			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	.0	.0	.0	.0	.0	.2		.0	.0	.3	.0	3.5	
NE	.2	.2	.0	.0	.0	.0	.0	.4		.1	.1	.5	.0	6.6	
E	.1	.2	.2	.0	.0	.0	.0	.5		.4	.0	.3	.1	13.2	
SE	.3	.2	.0	.0	.0	.0	.0	.5		.5	*	.3	.0	21.6	
S	.2	.1	.0	.0	.0	.0	.0	.3		.5	*	.3	.0	24.6	
SW	.2	.0	.1	.0	.0	.0	.0	.2		.2	.0	.1	.0	10.5	
W	.1	.0	.0	.0	.0	.0	.0	.1		.1	.0	.1	.0	6.8	
NW	.0	.0	.0	.0	.0	.0	.0	.0		.1	.0	.2	.0	2.7	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.1	.0	.0	.0	.0	.0	.0	.1		.0	.0	.6	.0	3.8	
TOT OBS	23	14	5	0	0	0	0		41	32	2	49	1	1739	1863
TOT PCT	1.2	.8	.3	.0	.0	.0	.0	2.2		1.7	.1	2.6	.1	93.3	

SEPTEMBER				PRECIPITATION TYPE								OTHER WEATHER PHENOMENA			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	*	.1	.1	.0	.0	.0	.0	.2		.0	.0	.6	.0	8.7	
NE	.2	.1	.1	.0	.0	.0	.0	.4		.1	.0	.8	.0	17.1	
E	.6	.3	.2	.0	.0	.0	.0	1.1		.2	.0	.7	.0	24.6	
SE	.4	.1	.2	.0	.0	.0	.0	.6		.8	.1	.1	.1	19.7	
S	.1	.1	.1	.0	.0	.0	.0	.3		.1	.1	.2	.0	12.0	
SW	.0	.0	.1	.0	.0	.0	.0	.1		.2	.0	.1	.0	2.9	
W	.1	.1	.1	.0	.0	.0	.0	.1		*	.0	.2	.0	1.5	
NW	.1	.0	.0	.0	.0	.0	.0	.1		.2	.1	.2	.0	2.4	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.1	.1	.6	.0	2.9	
TOT OBS	28	12	14	0	0	0	0		53	31	4	69	1	1756	1912
TOT PCT	1.5	.6	.7	.0	.0	.0	.0	2.8		1.6	.2	3.6	.1	91.8	

OCTOBER				PRECIPITATION TYPE								OTHER WEATHER PHENOMENA			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	.3	.0	.0	.0	.0	.5		.0	.1	.5	.0	15.7	
NE	.2	.1	.2	.0	.0	.0	.0	.5		.3	*	1.2	.0	18.7	
E	.3	.0	.2	.0	.0	.0	.0	.4		.1	.2	1.4	.0	22.6	
SE	.3	.1	.1	.0	.0	.0	.0	.4		.2	.0	.4	.0	16.7	
S	.1	.2	.1	.0	.0	.0	.0	.4		.2	.0	.1	.0	7.8	
SW	.0	*	.0	.0	.0	.0	.1	.1		.1	.1	.1	.0	2.1	
W	.1	.0	.1	.0	.0	.0	.0	.1		.0	.0	.0	.0	2.5	
NW	.1	.0	.1	.0	.0	.0	.0	.1		.0	.0	.3	.0	3.9	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.2	.0	2.0	
TOT OBS	20	10	20	0	0	0	1		45	18	7	77	0	1687	1834
TOT PCT	1.1	.5	1.1	.0	.0	.0	.1	2.5		1.0	.4	4.2	.0	92.0	

NOVEMBER				PRECIPITATION TYPE								OTHER WEATHER PHENOMENA			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.1	.1	.3	.0	.0	.0	.0	.5		.1	.3	.8	.0	16.7	
NE	.3	*	.3	.0	.0	.0	.0	.5		.2	.7	1.0	.0	12.2	
E	.4	.0	.4	.0	.0	.0	.0	.8		.1	.2	.8	.0	15.0	
SE	.1	.1	.1	.0	.0	.0	.0	.3		.2	.5	.9	.1	14.8	
S	.2	.1	.1	.0	.0	.0	.0	.4		.3	.4	.8	.0	14.9	
SW	.1	*	.0	.0	.0	.0	.0	.1		*	*	.1	.0	4.0	
W	.1	.0	.0	.0	.0	.0	.0	.1		.1	.1	.1	.0	3.4	
NW	*	.1	.1	.0	.0	.0	.0	.1		*	.1	.1	.0	6.4	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.2	.1	.0	1.9	
TOT OBS	23	6	19	0	0	0	0		46	18	42	75	1	1469	1647
TOT PCT	1.4	.4	1.2	.0	.0	.0	.0	2.8		1.1	2.6	4.6	.1	89.2	

DECEMBER				PRECIPITATION TYPE								OTHER WEATHER PHENOMENA			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	DUST BLWG DUST BLWG SNOW	NO SIG WEA	TOTAL OBS
N	.9	.1	.5	.0	.0	.0	.0	1.5		.1	.6	.3	.0	15.2	
NE	.4	.1	.1	.0	.0	.0	.0	.7		.1	.4	.8	.0	15.1	
E	.3	.0	.6	.0	.0	.0	.0	.9		*	.7	1.1	.0	13.4	
SE	.6	.1	.4	.0	.0	.0	.0	1.1		.1	.6	1.9	.0	14.6	
S	.2	.2	.1	.0	.0	.0	.0	.5		.4	.3	.5	.0	11.7	
SW	.1	.0	.0	.0	.0	.0	.0	.1		.1	.2	.1	.0	3.6	
W	*	.0	.0	.0	.0	.0	.0	*		.0	.2	.4	.0	3.3	
NW	*	.1	*	.0	.0	.0	.0	.1		.0	.3	.5	.0	7.0	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	
CALM	.0	.0	.0	.0	.0	.0	.0	.0		.0	.2	.1	.0	1.2	
TOT OBS	41	9	27	0	0	0	0		76	15	54	86	0	1303	1530
TOT PCT	2.7	.6	1.8	.0	.0	.0	.0	5.0		1.0	3.5	5.6	.0	85.2	

TABLE F-11. (continued)

AREA: Galveston - Freeport

CENTRAL POSITION: 28° 30'N 95° 01'W

PERCENTAGE FREQUENCY OF WIND DIRECTION BY SPEED AND BY HOUR

	WIND SPEED (KNOTS)									HOUR (GMT)							
WND DIR	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS	PCT FREQ	MEAN SPD	00	03	06	09	12	15	18	21
N	.7	3.6	4.8	1.7	.2	*		11.1	12.9	9.9	9.4	10.6	10.2	12.0	12.8	11.8	12.0
NE	.7	5.1	5.4	1.1	.1	*		12.4	12.1	12.5	11.4	9.8	12.1	12.7	14.5	14.4	13.1
E	1.2	8.2	6.8	.7	*	*		17.0	11.0	19.0	17.2	16.2	17.2	14.9	13.0	17.9	20.4
SE	1.4	12.0	9.6	.6	*	*		23.6	10.8	23.7	26.2	28.3	24.0	21.6	20.6	20.9	23.8
S	1.4	9.1	6.8	.6	*	*		18.0	10.7	17.3	16.2	18.8	19.5	20.0	17.7	16.7	14.2
SW	.6	3.4	1.6	.1	*	.0		5.7	9.4	5.2	7.8	5.1	4.8	6.6	7.2	5.5	5.1
W	.4	2.2	1.2	.1	*	*		4.0	10.2	4.2	2.7	3.2	3.7	4.4	4.1	4.4	2.6
NW	.4	2.0	2.0	.8	.1	*		5.2	12.4	4.9	5.7	4.6	4.4	5.1	5.8	5.8	6.7
VAR	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	3.0							3.0	.0	3.2	3.4	3.3	4.1	2.8	4.3	2.6	2.3
TOT OBS	2399	11093	9203	1380	104	20	24199		11.1	4915	789	5737	582	4526	603	6571	476
TOT PCT	9.8	45.6	38.2	5.9	.4	.1		100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PERCENTAGE FREQUENCY OF WEATHER OCCURRENCE BY WIND DIRECTION

	PRECIPITATION TYPE									OTHER WEATHER PHENOMENA			DUST			
WND DIR	RAIN	RAIN SHWR	DRZL	FRZG PCPN	SNOW	OTHER FRZN PCPN	HAIL	PCT FREQ PCPN AT OB TIME	TOTAL PCPN OBS	THDR LTNG	FOG WO PCPN	SMOKE HAZE	BLWG BLWG	DUST SNOW	NO SIG WEA	TOTAL OBS
N	.2	.1	.2	*	.0	.0	*	.5		*	.3	.5		.1	9.9	
NE	.2	.1	.2	.0	.0	*	.0	.4		.1	.3	.6		*	11.0	
E	.3	.1	.3	.0	.0	.0	.0	.6		.2	.4	1.0		*	14.9	
SE	.3	.1	.1	.0	.0	.0	.0	.5		.3	.7	1.9		*	20.1	
S	.2	.1	.1	.0	.0	.0	.0	.4		.2	.5	1.1		*	16.0	
SW	.1	*	*	.0	.0	.0	*	.1		.1	.1	.2		*	5.1	
W	.1	*	*	.0	.0	.0	.0	.1		*	.1	.2		*	3.7	
NW	.1	*	*	.0	.0	.0	*	.1		*	.1	.2		*	4.5	
VAR	.0	.0	.0	.0	.0	.0	.0	.0		.0	.0	.0		.0	.0	
CALM	*	.0	*	.0	.0	.0	.0	*		*	.2	.4		.0	2.3	
TOT OBS	295	89	192	1	0	1	3		552	215	495	1233		26	18171	20668
TOT PCT	1.5	.4	1.0	*	.0	*	*	2.7		1.0	2.6	6.1		.1	87.5	

PCT FREQ OF TOTAL CLOUD AMOUNT (EIGHTHS)
BY WIND DIRECTION

WND DIR	0-2	3-4	5-7	8 & OBSCD	TOTAL OBS	MEAN CLOUD COVER
N	4.5	1.2	2.3	3.2		4.1
NE	4.5	1.8	2.7	3.5		4.3
E	5.5	3.5	4.3	3.9		4.3
SE	7.9	5.3	6.3	3.9		4.1
S	6.3	4.5	4.7	2.6		4.0
SW	2.3	1.4	1.2	.7		3.4
W	1.9	.8	.8	.6		3.2
NW	2.3	.7	1.0	1.1		3.7
VAR	.0	.0	.0	.0		.0
CALM	1.6	.5	.4	.3		2.7
TOT OBS	6902	3812	4463	3540	18717	4.0
TOT PCT	36.7	19.7	23.8	19.8	100.0	

WIND SPEED (KTS) VS SEA HEIGHT (FT)

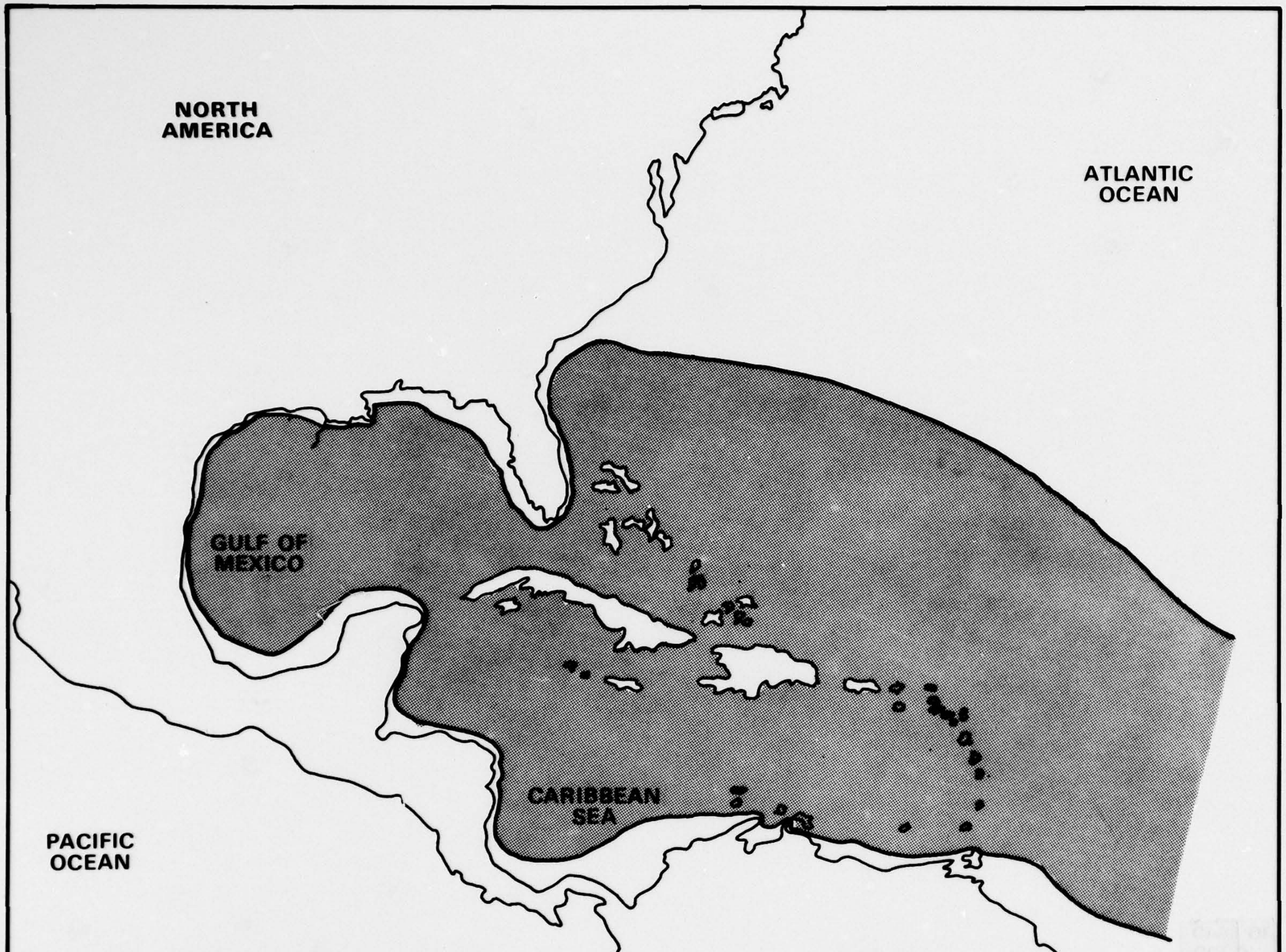
HGT	0-3	4-10	11-21	22-33	34-47	48+	PCT	TOT OBS
<1	4.5	7.4	.4	.0	.0	.0	12.4	
1-2	1.1	21.2	7.4	.0	.0	.0	29.7	
3-4	.3	10.4	19.4	1.2	.0	.0	31.2	
5-6	*	2.0	11.5	2.1	*	.0	15.7	
7	.0	.3	3.9	2.1	.1	.0	6.5	
8-9	*	.2	1.1	1.4	.1	*	2.7	
10-11	.0	*	.3	.6	*	.0	.9	
12	.0	.0	.1	.3	.1	.0	.5	
13-16	.0	.0	.0	.2	.1	.0	.2	
17-19	.0	.0	.0	*	*	.0	.1	
20-22	.0	.0	.0	.0	*	*	*	
23-25	.0	.0	.0	.0	.0	*	*	
26-32	.0	.0	.0	.0	.0	.0	.0	
33-40	.0	.0	.0	.0	.0	.0	.0	
41-48	.0	.0	.0	.0	.0	.0	.0	
49-60	.0	.0	.0	.0	.0	.0	.0	
61-70	.0	.0	.0	.0	.0	.0	.0	
71-86	.0	.0	.0	.0	.0	.0	.0	
87+	.0	.0	.0	.0	.0	.0	.0	
TOT PCT	6.0	41.5	44.1	7.9	.5	.1	100.0	4662

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	9.1	22.5	20.9	6.9	1.6	.7	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	11341	3
6-7	.4	2.4	7.2	7.0	2.8	1.2	.3	.2	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	3929	5
8-9	.1	.5	.8	1.4	1.2	.7	.3	.2	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	946	6
10-11	.0	.4	.3	.3	.3	.2	.2	.1	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	350	6
12-13	.0	.0	.2	.1	.1	.1	.1	*	*	.0	*	.0	.0	.0	.0	.0	.0	.0	.0	107	6
>13	.0	.0	.0	.1	*	.1	.1	.1	.1	.0	*	*	*	.0	.0	.0	.0	.0	.0	70	11
INDET	5.1	1.2	.9	.5	.2	.1	.1	*	*	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1507	1
TOTAL	2739	4975	5552	2935	1106	543	182	117	69	14	14	3	1	0	0	0	0	0	0	18250	3
PCT	14.7	27.0	30.4	16.3	6.2	3.1	1.0	.7	.4	.1	.1	*	*	.0	.0	.0	.0	.0	.0	100.0	

Source: Same as Table F-1

TABLE F-12. ANNUAL SUMMARIES OF MARINE WEATHER OBSERVATIONS.

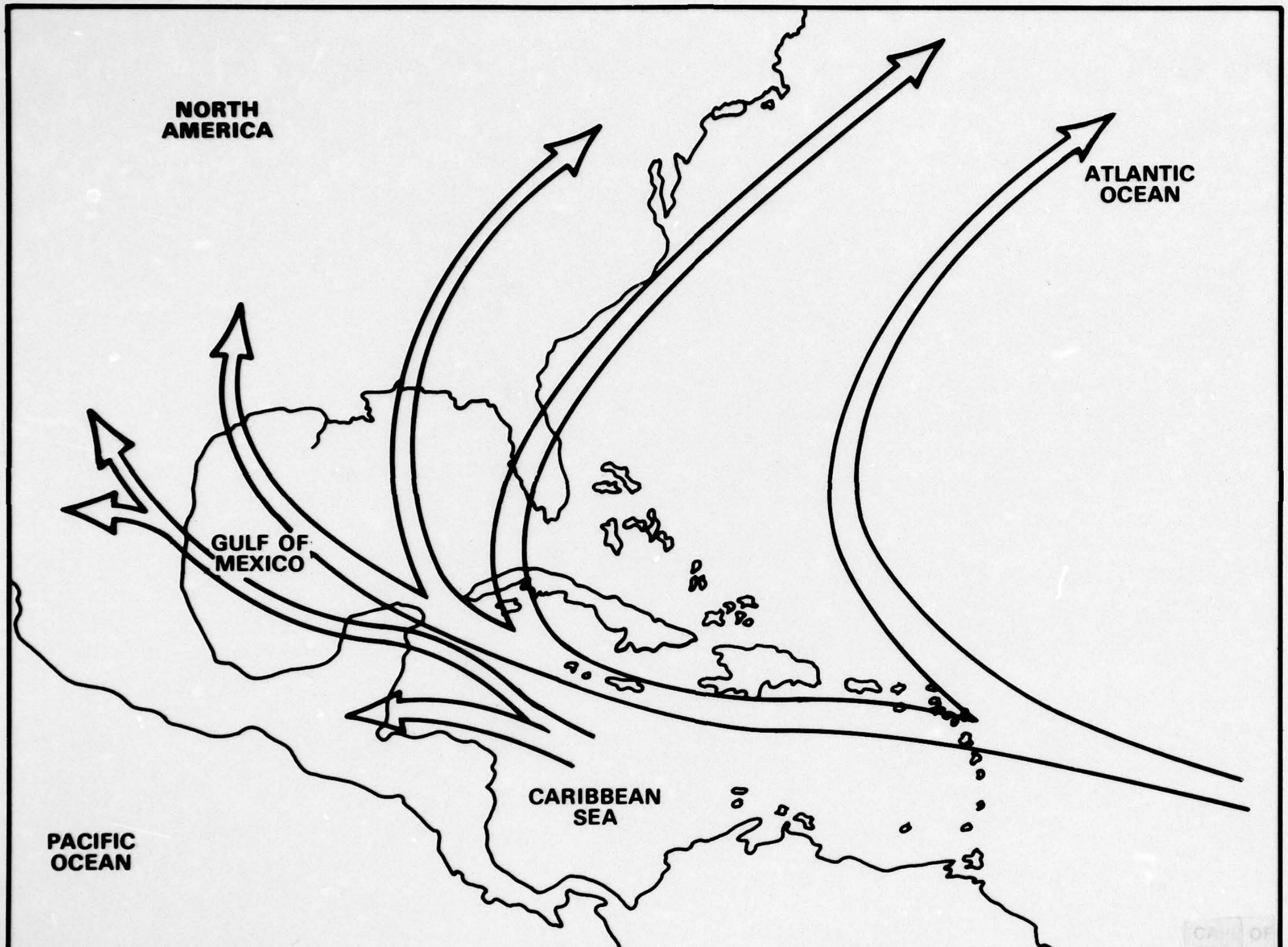


SOURCE: *Mariner's Worldwide Guide to Tropical Storms at Sea,* H. L. Crutcher and R. G. Quayle.

FIGURE F-1. REGIONS OF TROPICAL CYCLOGENESIS IN THE ATLANTIC OCEAN AREA

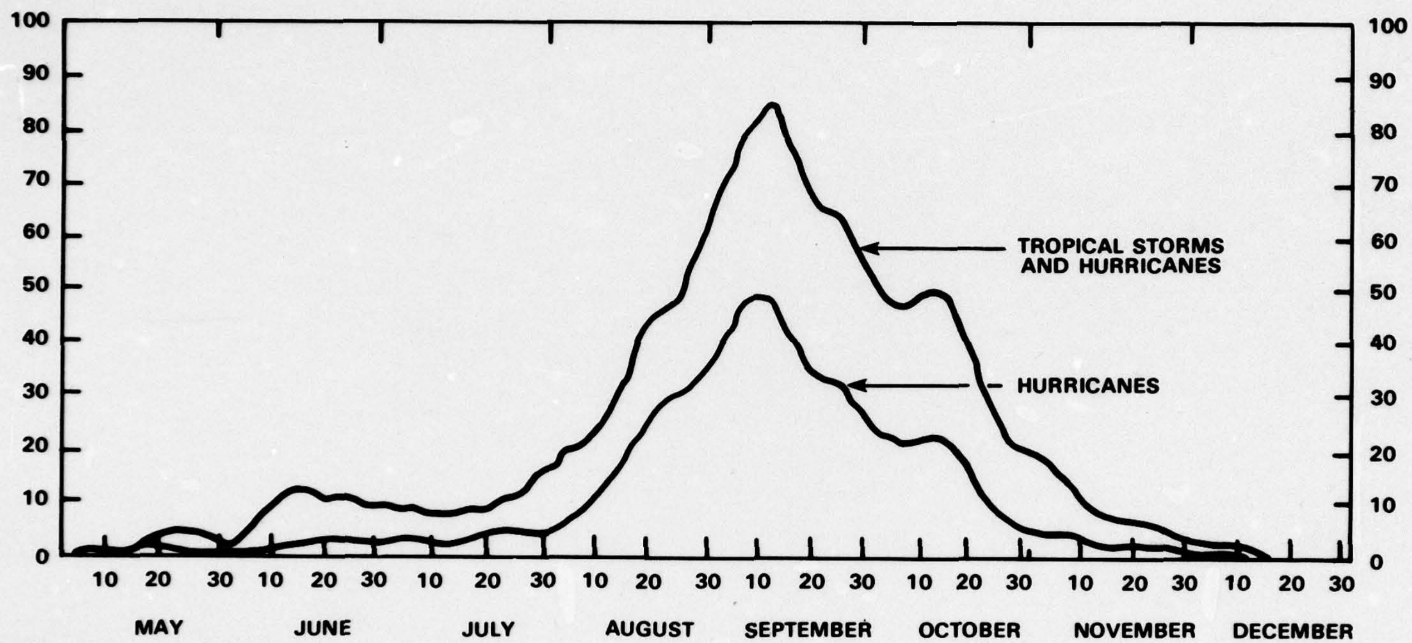
shown in figure F-1, this area extends eastward as far as the Cape Verde Islands off the west coast of Africa. In this area, tropical cyclones which have winds of 34 to 63 knots are known as tropical storms, and those with winds of 64 knots or greater are termed hurricanes. Hurricanes do not occur as often as storms in higher latitudes, however, they are much more destructive than any other type of storm. Mariners who navigate in ocean areas subject to tropical cyclone activity must be constantly alert to detect the approach of these dangerous storms. The fact that the storm center is relatively small, and excellent weather exists only a few hundred miles away should not lull the mariner into a false sense of security. The suddeness with which the weather can deteriorate as the storm approaches is difficult to envision by a person who has not experienced this phenomenon.

Typically, tropical cyclones in the North Atlantic Ocean area move with the prevailing winds. Figure F-2 shows the usual tracks of tropical storms which are normally curved. The storms usually move westward at first, then northwestward, and finally northeastward. Some, however, continue westward and never curve appreciably to the north, staying in low latitudes. Peculiar movements by tropical storms are not uncommon, and have lead to various descriptive terms such as: right hooker, south drooper, fish hooker, inside looper, etc. These storms rarely move to the southeast and such movements are of short duration. The entire Caribbean, the Gulf of Mexico, the coasts which border on these bodies of water, and the Atlantic Coast of the U.S. are subjected to these storms during the hurricane season, which is normally from June through October, although there are occurrences in other months, notably May and November. Figure F-3 shows a graph of tropical storms and hurricanes in the North Atlantic Ocean area by month over a 92-year period. As can be seen, August and September are the months of greatest activity. Figures F-4 and F-5 show that an average of 9 tropical storms occur each year, of which 5 reach hurricane strength. June and July storms usually develop in the northwestern Caribbean or Gulf of Mexico, whereas in August this formation occurs to the east of the Lesser Antilles. In September, storms are generated : between 50° W longitude and the Lesser Antilles; in the southern part of the Gulf of Mexico; the western part of the Caribbean; near the Bahamas; and in the vicinity of the Cape Verde Islands. October storms generally form in the western Caribbean, while storms in other months outside the normal hurricane season can occur anywhere within the area shown on figure F-1, with some preference for the southwestern Caribbean Sea. Figure F-6 shows the average number of tropical cyclones per year in the North Atlantic Ocean area by area of occurrence.



SOURCE: *Mariner's Worldwide Climatic Guide to Tropical Storms at Sea,* H. L. Crutcher and R. G. Quayle

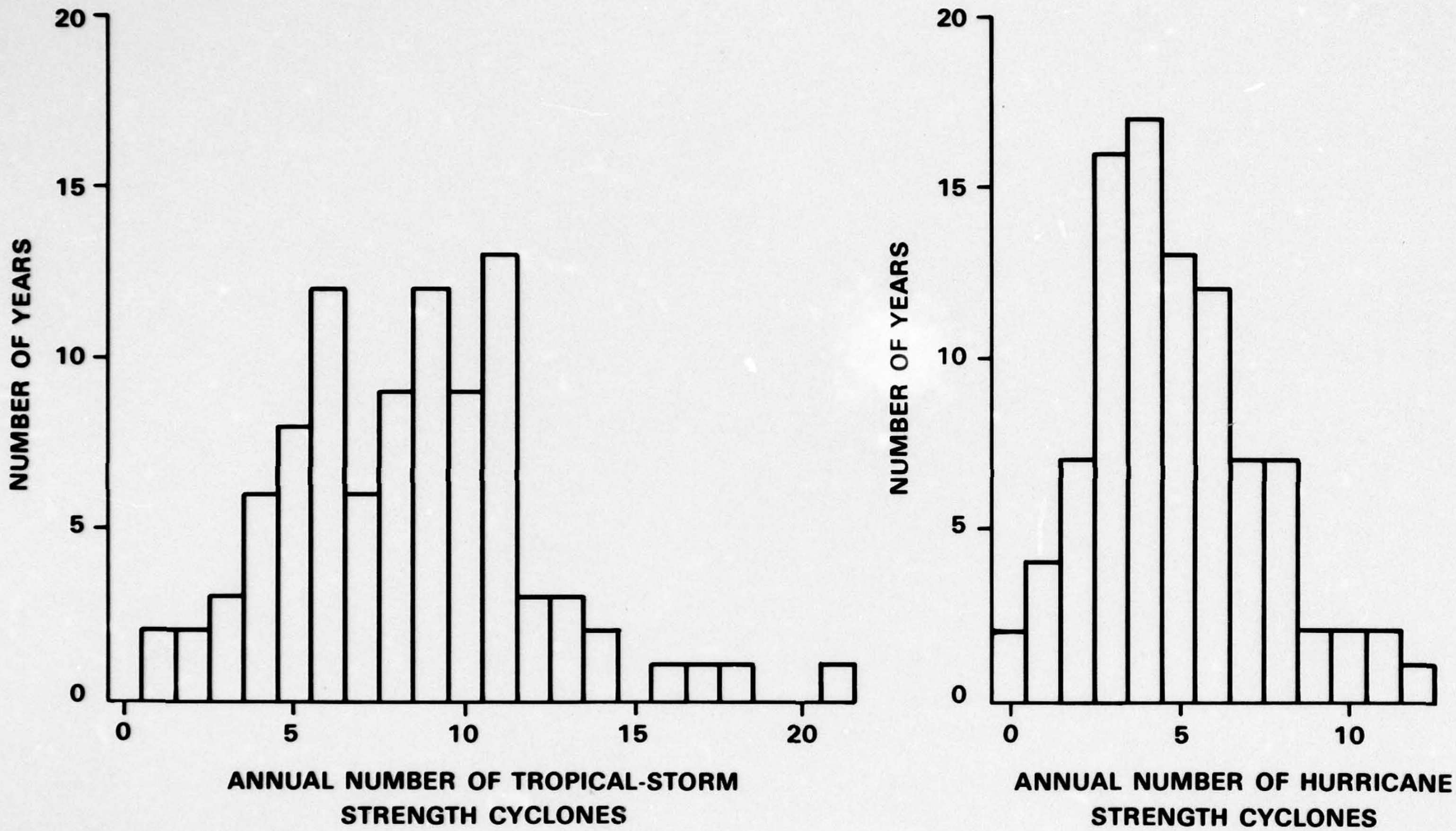
FIGURE F-2. PREFERRED TRACKS FOR TROPICAL STORMS—DATA FOR ENTIRE YEAR SUMMARIZED



NOTE: DATA FROM 1886 THROUGH 1977, SMOOTHED ON A NINE-DAY MOVING AVERAGE

SOURCE: Neuman, C. J. and Cry, G. W., "A Revised Atlantic Tropical Cyclone Climatology," *Mariner's Weather Log*, July 1978.

FIGURE F-3. DAILY OBSERVATIONS OF NORTH ATLANTIC OCEAN TROPICAL STORMS AND HURRICANES



SOURCE: Neuman, C. J., and Cry, G. W., "A Revised Atlantic Tropical Cyclone Climatology," *Mariners' Weather Log*, July 1978.

FIGURE F-4. FREQUENCY DISTRIBUTION OF ANNUAL TROPICAL CYCLONES 1886-1977

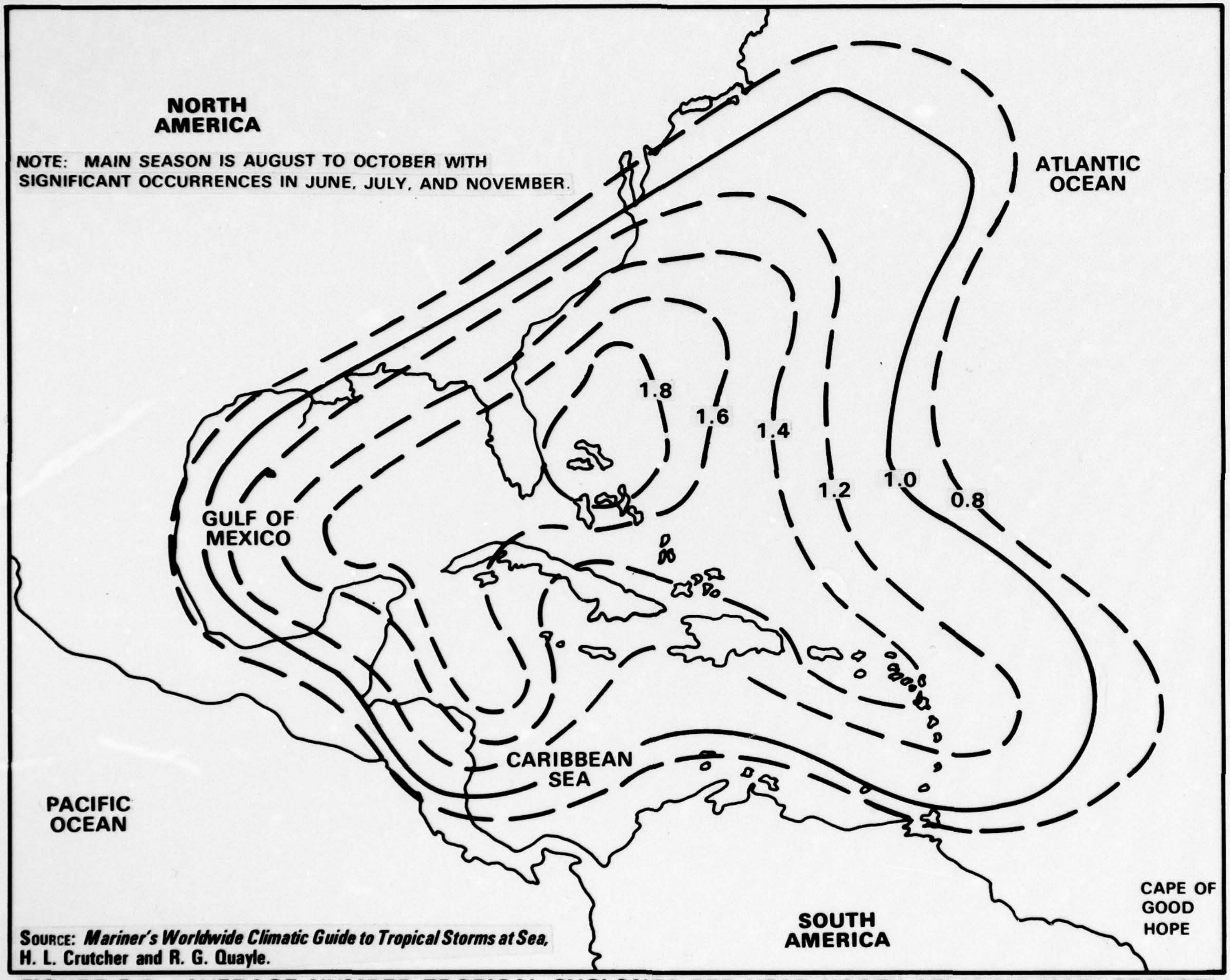
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
TROPICAL STORMS	*	*	*	*	0.1	0.4	0.3	1.0	1.5	1.2	0.4	*	4.2
HURRICANES	*	*	*	*	*	0.3	0.4	1.5	2.7	1.3	0.3	*	5.2
TROPICAL STORMS AND HURRICANES	*	*	*	*	0.2	0.7	0.8	2.5	4.3	2.5	0.7	0.1	9.4

* — Less than .05

Monthly values cannot be combined since individual storms which overlap two months were counted once in each month and once in the annual.

SOURCE: ***Mariner's Worldwide Climatic Guide to Tropical Storms at Sea,***
H. L. Crutcher and R. G. Quayle. U.S. Naval Weather Service Command.
U.S. Government Printing Office, Washington, D.C., 1974.

FIGURE F-5. MONTHLY STORM FREQUENCIES FOR THE NORTH ATLANTIC OCEAN CARIBBEAN SEA, AND GULF OF MEXICO



SOURCE: *Mariner's Worldwide Climatic Guide to Tropical Storms at Sea,* H. L. Crutcher and R. G. Quayle.

FIGURE F-6. AVERAGE NUMBER TROPICAL CYCLONES PER YEAR NORTH ATLANTIC MAIN SEASON

The average speed of movement of tropical cyclones in the tropics is 10 to 12 knots. This speed varies with the location of the storm and adjacent weather conditions. Higher speeds occur as the storms move into the higher latitudes as shown on figure F-7.

Although there is an extensive network of radio stations in the Atlantic Ocean area which broadcasts information on tropical cyclones (see Weather Broadcasts[1]), knowledge of the signs of approach of these storms is useful information for the mariner to have at his disposal. Being present in a vessel at sea during the passage of a hurricane is an awesome experience which most mariners would rather forego.

The earliest indication of the approach of a tropical cyclone is the swell which develops in the right rear quadrant, known by mariners as the "dangerous semicircle," and moves out ahead of the storm in its approximate direction of travel. The frequency of the swell waves is a guide to storm intensity; the more intense the storm, the fewer are the swell waves per minute. A fully developed hurricane far out in the Gulf of Mexico generally causes 4 or 5 swell waves per minute, whereas in ordinary weather there are 12 to 15 waves in one minute. These swells are generally twice as long as the normal swells and may be observed several days before the storm's arrival.

When the center of the storm is 500 to 1,000 miles away, there is a slight rise in the barometer and the clear skies give no hint of the approaching storm. If clouds are present, they are few and cumulus clouds have no vertical development. The barometer begins "pumping," that is, going up and down several hundreths of an inch.

As the storm approaches, white cirrus clouds, nicknamed "mare's tails," appear and seem to converge in the direction of the storm, which is by now 300 to 600 miles distant. This phenomenon is more pronounced at sunrise and sunset. At this time, the barometer starts a slow, steady fall. Cloud formations become more confused and develop into a continuous haze of cirrostratus. These clouds become more dense, and fine, mist-like showers develop. The barometer falls more rapidly, and the wind gusts from 22 to 40 knots. In the direction of the storm a very dark area of heavy cumulonimbus clouds form. This wall of clouds is called the "bar." Parts of this heavy cloud formation seem to break away and drift across the sky as

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1. PRC Systems Services Company, Deepwater Ports Approach/Exit-Technology/Service Alternatives, prepared for the U.S. Coast Guard, February 1979.

AD-A074 529 PLANNING RESEARCH CORP MCLEAN VA F/G 15/5
DEEPWATER PORTS APPROACH/EXIT HAZARD AND RISK ASSESSMENT.(U)
FEB 79 W E FARAGHER, J T PIZZO, L R REINBURG DOT-CG-60351-A
UNCLASSIFIED USCG-D-6-79 NL

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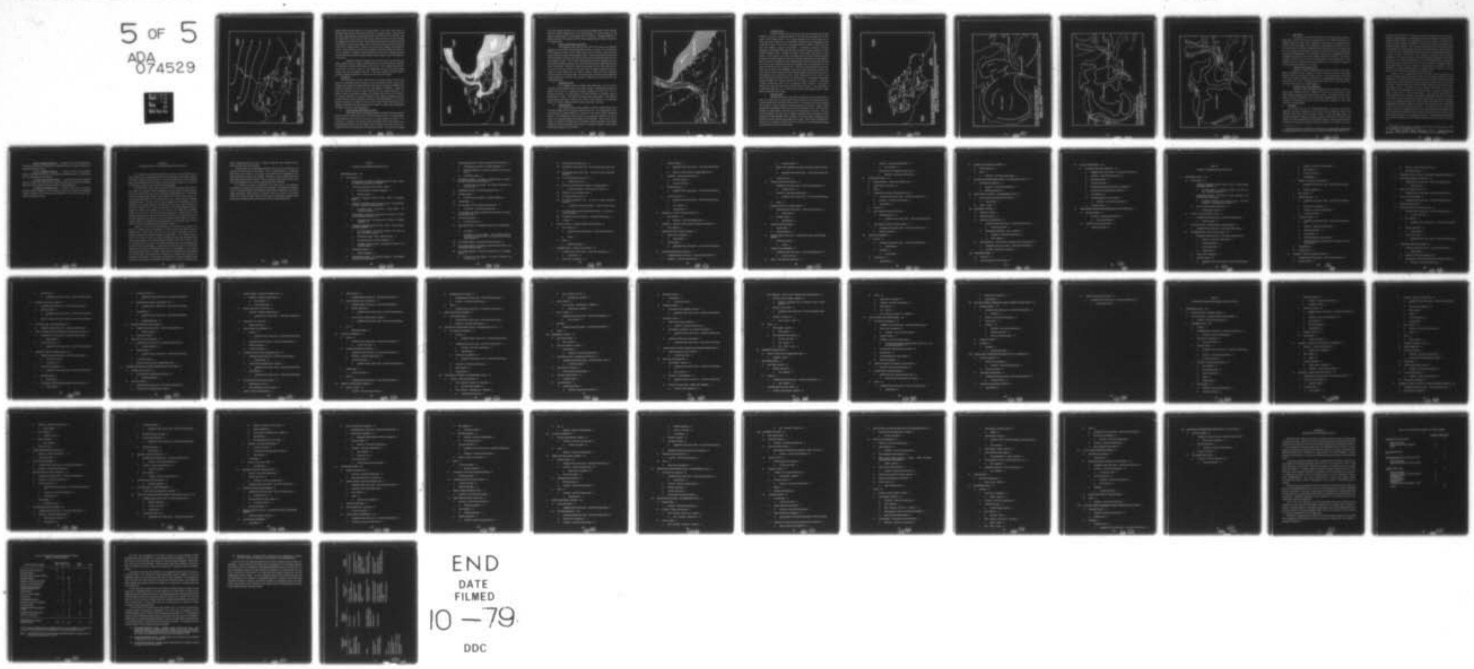

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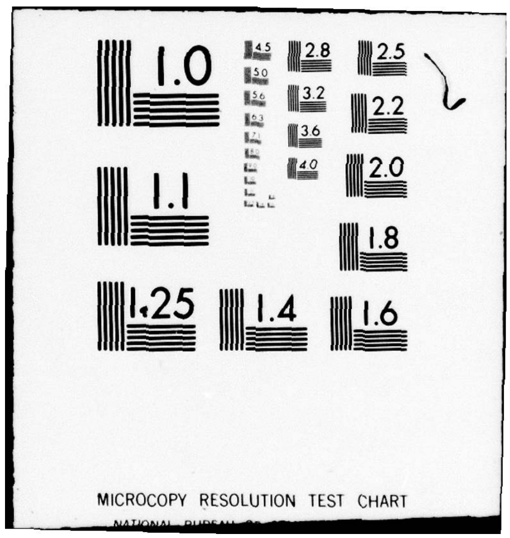
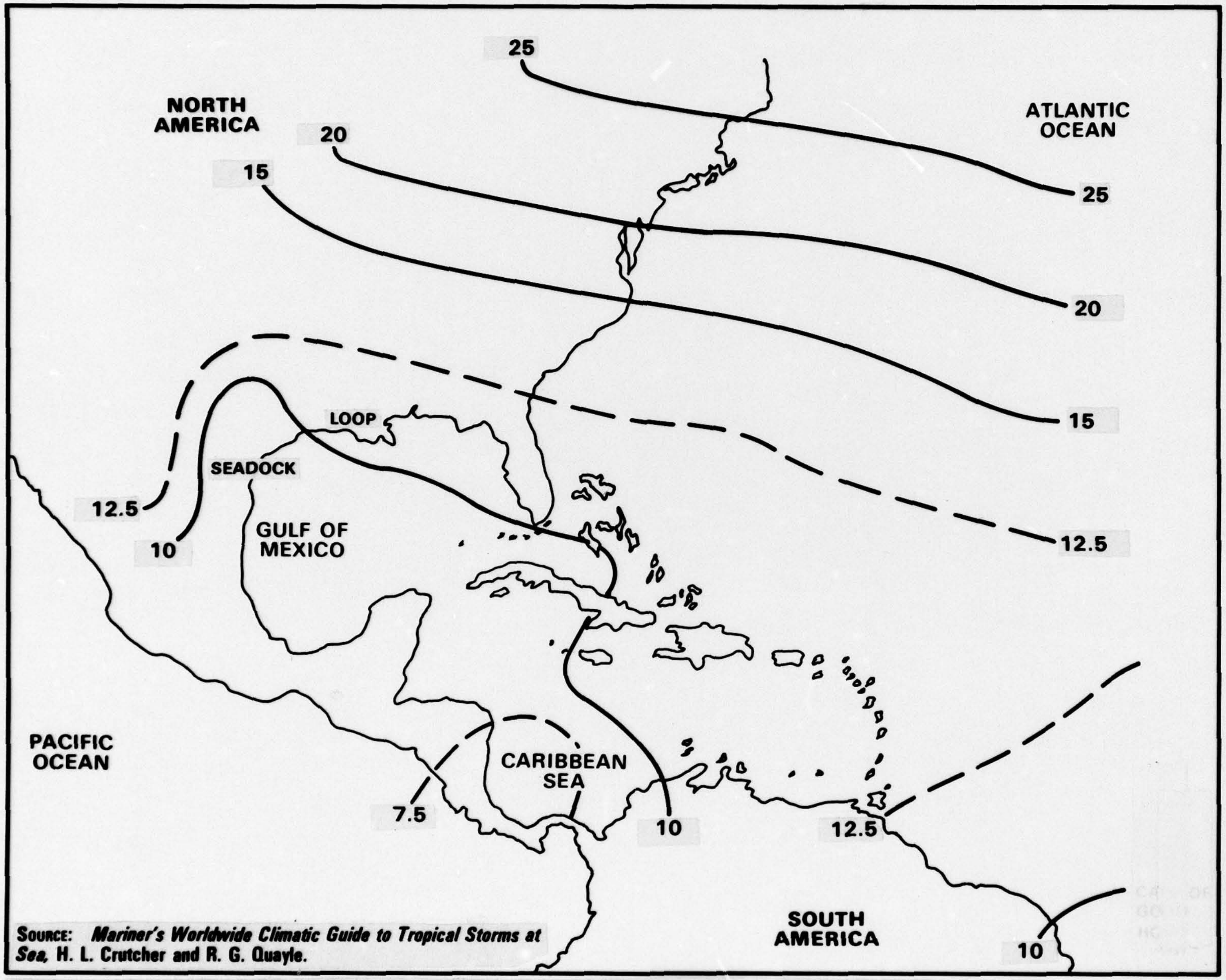

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART



SOURCE: *Mariner's Worldwide Climatic Guide to Tropical Storms at Sea,* H. L. Crutcher and R. G. Quayle.

FIGURE F-7. AVERAGE SPEED OF STORM MOVEMENT (KNOTS)—SCALAR MEAN SPEEDS ENTIRE YEAR

squalls develop and the speed of the wind increases. As the "bar" draws near, the barometer falls rapidly and the wind continues to increase in speed. The arrival of the "bar" brings darkness, continual squalls, and a rapid increase in wind speed. Now 100 to 200 miles away, the storm center comes closer and the wind screams through the rigging, as torrential rains fall. The seas become mountainous, and the increasing wind blows the tops off huge waves which combines with the rain to reduce visibility to less than a hundred yards. Vessels of any size become sluggish and difficult to control. Large vessels may receive heavy damage, and smaller vessels may break up. It is not possible to navigate in these conditions; survival is the overriding concern. Mariners who have survived this experience go to great lengths to avoid its repetition in the future.

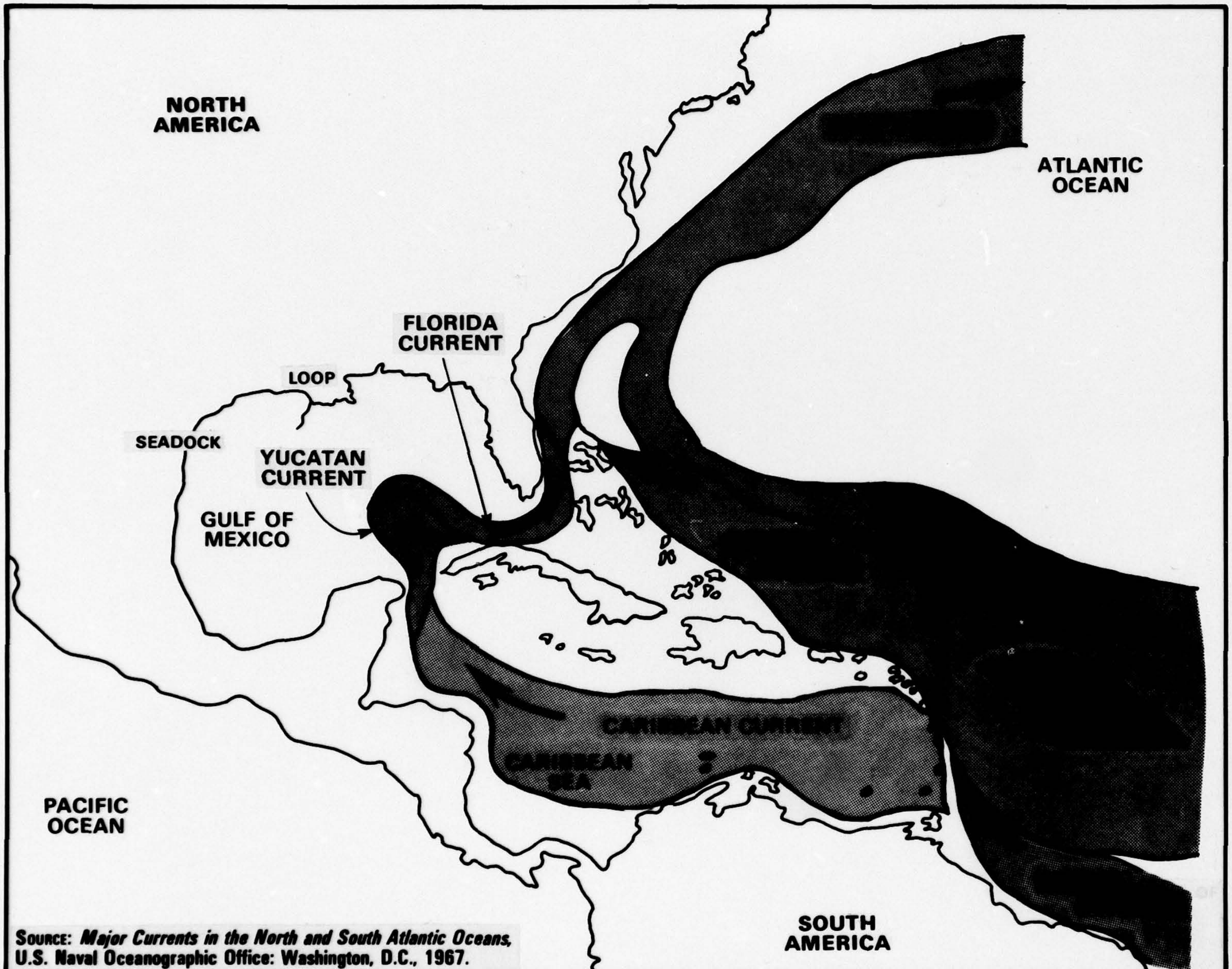
Should the vessel go through the eye of the storm, the wind and rain cease, patches of blue sky appear overhead, and the sea is mountainous but confused. The barometer reaches its lowest point, which may be 1.5 to 2 inches below normal. As the wall, or the other side of the eye approaches, the wind fury strikes again suddenly, but from the opposite direction. As the storm passes, the whole sequence previously described takes place in reverse, but this time more rapidly.

3. CURRENTS

The entire surface of every oceanic area is in constant motion. Much of this motion is exceedingly variable; however, major well-defined currents do exist, and although more research is needed, sufficient information is available to describe their locations, boundaries, set, and drift with a fair degree of reliability. Figure F-8 shows the location, extent and major direction of the principal currents in the Western Atlantic Ocean area, including the Caribbean Sea and the Gulf of Mexico. The currents shown have an important influence on the routes, for example, which an oil tanker would use when travelling to and from LOOP and SEADOCK. For a more specific discussion, see chapter VI of this report titled "Hazard Identification and Ranking." Descriptions of the currents shown in figure F-8 should help to understand the effect they have on vessel navigation.

a. Guiana Current (North Brazil Current)

The Guiana Current is a strong, consistent northwest current along the northeast coast of South Africa from 5° south latitude to about 12° north latitude, whose speed can vary from 0.2 to 4.2 knots in a steady direction of 303°T. It is formed by a portion of the Atlantic South Equatorial Current which flows in a northwestward direction off Cape Natal, and is reinforced to some extent in its northern section by the Atlantic North Equatorial Current. The current is stronger



SOURCE: ***Major Currents in the North and South Atlantic Oceans,***
U.S. Naval Oceanographic Office: Washington, D.C., 1967.

FIGURE F-8. MAJOR CURRENTS IN THE NORTH ATLANTIC OCEAN AREA

from July through December in the area between the equator and 7° north latitude, and from January through June in the areas between 5° south latitude and the equator, and between 7° north latitude and 12°N latitude. Strongest speeds are in the area between 1°N latitude and 6°N latitude, probably due to the heavy outflow of the Amazon River.

b. Atlantic North Equatorial Current

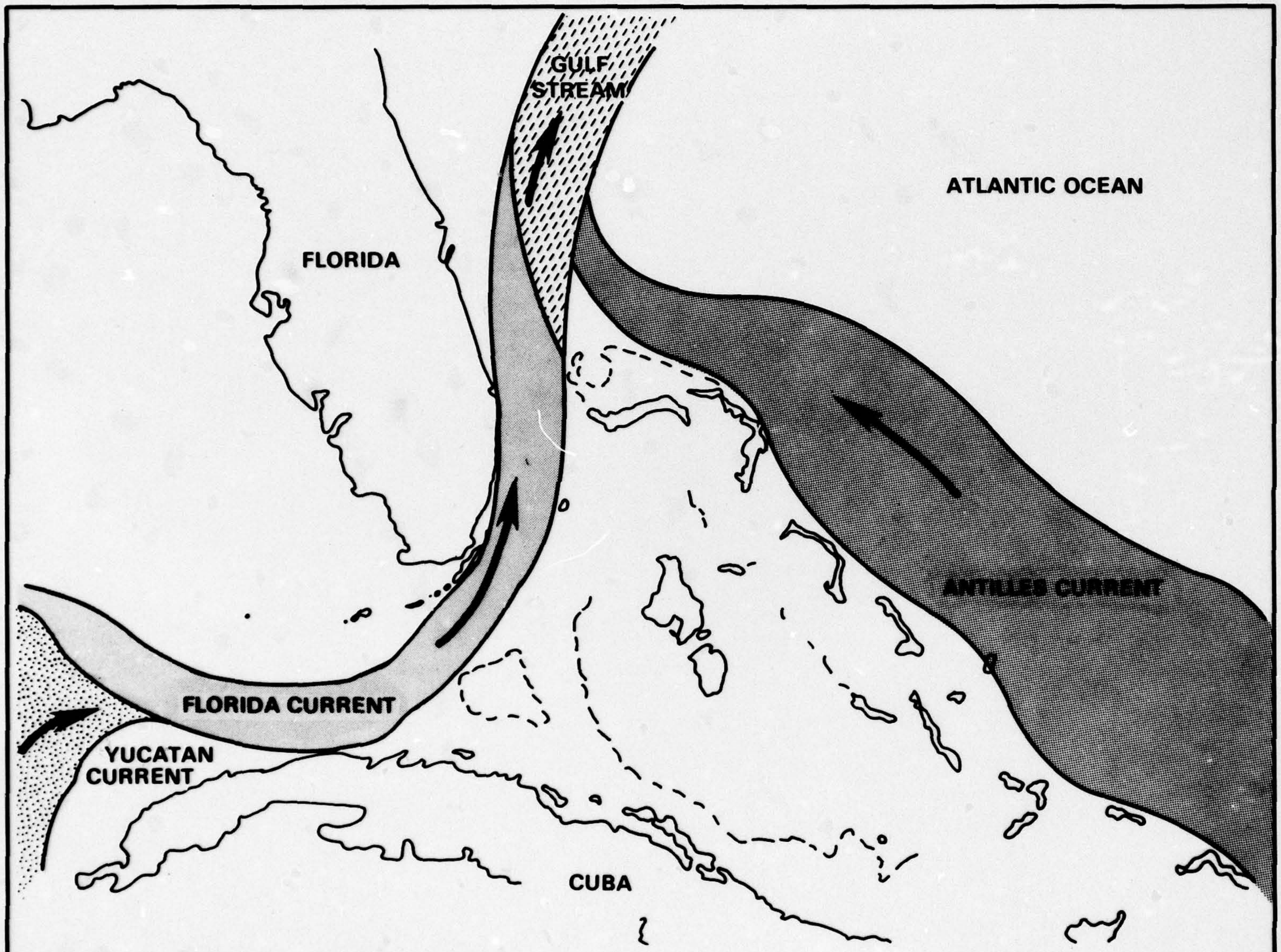
The northeast trade winds are the cause of the wide, slow, generally westerly set of the Atlantic North Equatorial Current. Its origin is in the vicinity of 26°W longitude between 15° and 30°N latitude, and from there it flows westward across the ocean to about 60°W longitude, where it forms the Antilles Current north of the West Indies, and joins the Guiana Current east of the Windward Islands to form the Caribbean Current. The Atlantic North Equatorial Current migrates north and south several hundred miles due to the movement of the Azores High, being furthest north in the summer. Mean drift is higher in the southern than in the northern part of the current, and lower overall in the winter when the Atlantic Equatorial Countercurrent is poorly defined and the westerly Atlantic North and South Equatorial Currents join near 9° north latitude. The mean drift of the Atlantic North Equatorial Current varies from 0.5 knots from January through June to 0.6 knots from July through December.

c. Caribbean Current

The Caribbean Current, although little publicized, is one of the most consistent and well-defined of the major ocean currents. Its boundaries are shown in figure F-8, and its set is generally westerly throughout the year from 65 to 75 percent of the time. Its mean speed is 0.9 knots, however, its maximum speed is occasionally 3.5 knots. The band of maximum speed is generally in the southerly portion of the area shown in figure F-8. There is little variation in its persistent western set, which is influenced by the stable trade winds in the area.

d. Antilles Current

The Antilles Current, whose location is shown in figures F-8 and F-9, has little seasonal variation in speed, direction and size. The current begins in the area around the Leeward Islands as a portion of the North Atlantic Equatorial Current. The stronger part of the current is in its southern extremity as it flows close to the Leeward Islands, the Antilles, and the Bahamas. Speed varies from as little at 0.1 knots in its northern area to as high as 2 knots in the south. In the winter months, as the Bermuda High moves south, the northern boundary of the Antilles Current also migrates in that direction.



SOURCE: *Major Currents in the North and South Atlantic Oceans*, U. S. Naval Oceanographic Office: Washington, D.C., 1967.

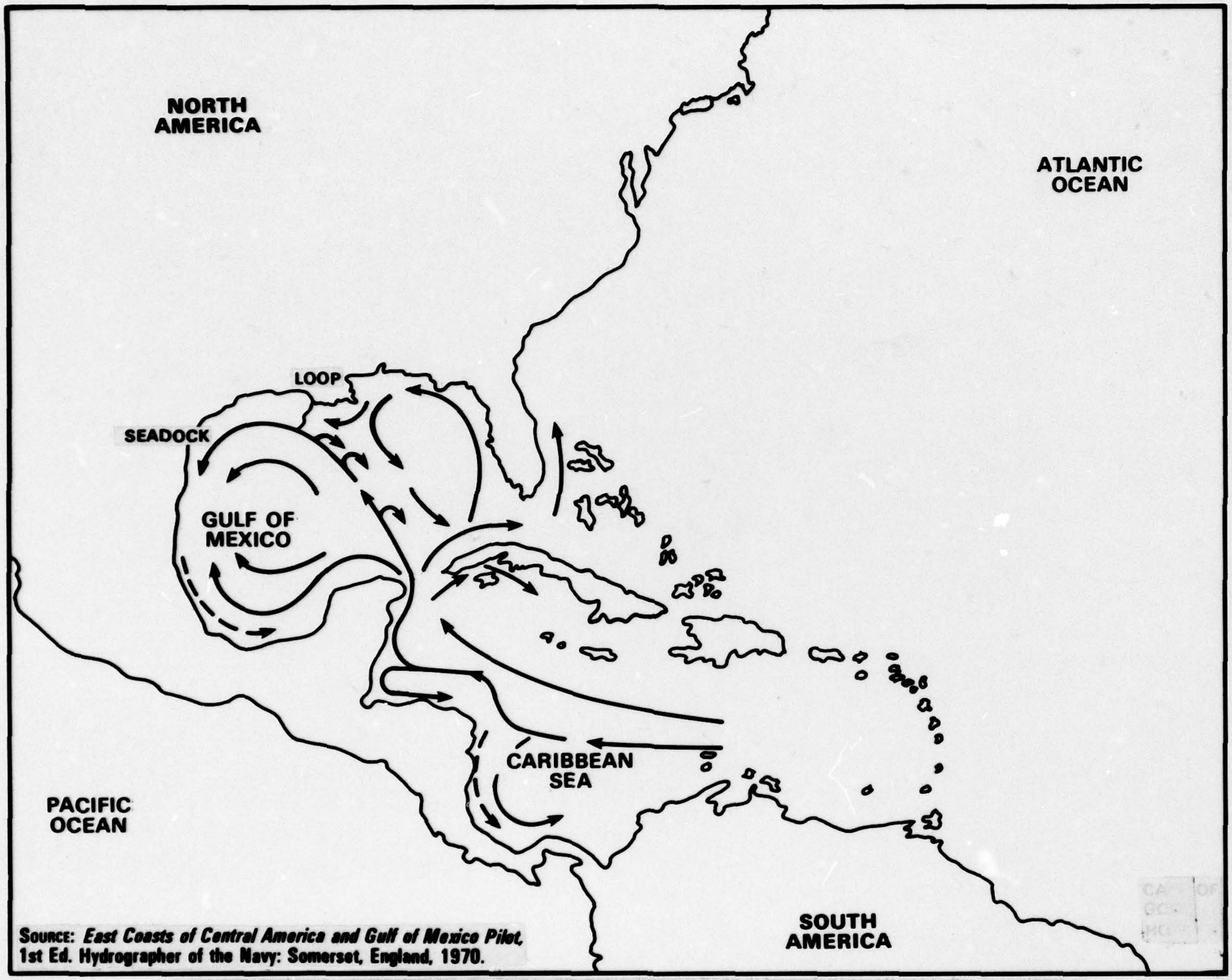
FIGURE F-9 MAJOR CURRENTS STRAITS OF FLORIDA AREA

e. Yucatan Current

As shown in figure F-8, the Yucatan Current flows through the Yucatan Channel in a north to northwesterly direction. Its main axis is generally west of the center of the Channel nearer to the Yucatan Peninsula than to the western tip of Cuba, and varies in speed from 1 to sometimes as high as 4 knots, although the mean is less than 2 knots. The current is strongest and most constant in April, May, and June, then weakens in August and September. It reaches its weakest in October, November and December, becoming stronger in January, February, and March. East of 86°W longitude, which is roughly the center of the channel, the current is much weaker. In all seasons of the year, the large volume of water flowing northward through the Yucatan Channel into the Gulf of Mexico spreads west across Campeche Bank, the Gulf of Campeche, and the Sigsbee Deep, northwest toward Galveston and Port Arthur, north northwest toward the Mississippi River, and eastward into the Straits of Florida as shown in figure F-10. A line from Cayo Buenavista on the northwest coast of Cuba to the Mississippi River Delta forms the division between the flows into the Gulf of Mexico from the Yucatan Channel (see figure F-10). West of this boundary, the currents flow north or west; while east of it, the flow is east toward the Straits of Florida to form the Florida Current. The position of the strong current between the Yucatan Channel and the Straits of Florida is extremely variable, moving from close to the northwestern coast of Cuba to a loop which extends more than 300 miles north into the Gulf of Mexico. This circulation is occasionally referred to as the Loop Current, which may actually become a large eddy or eddies from time to time.

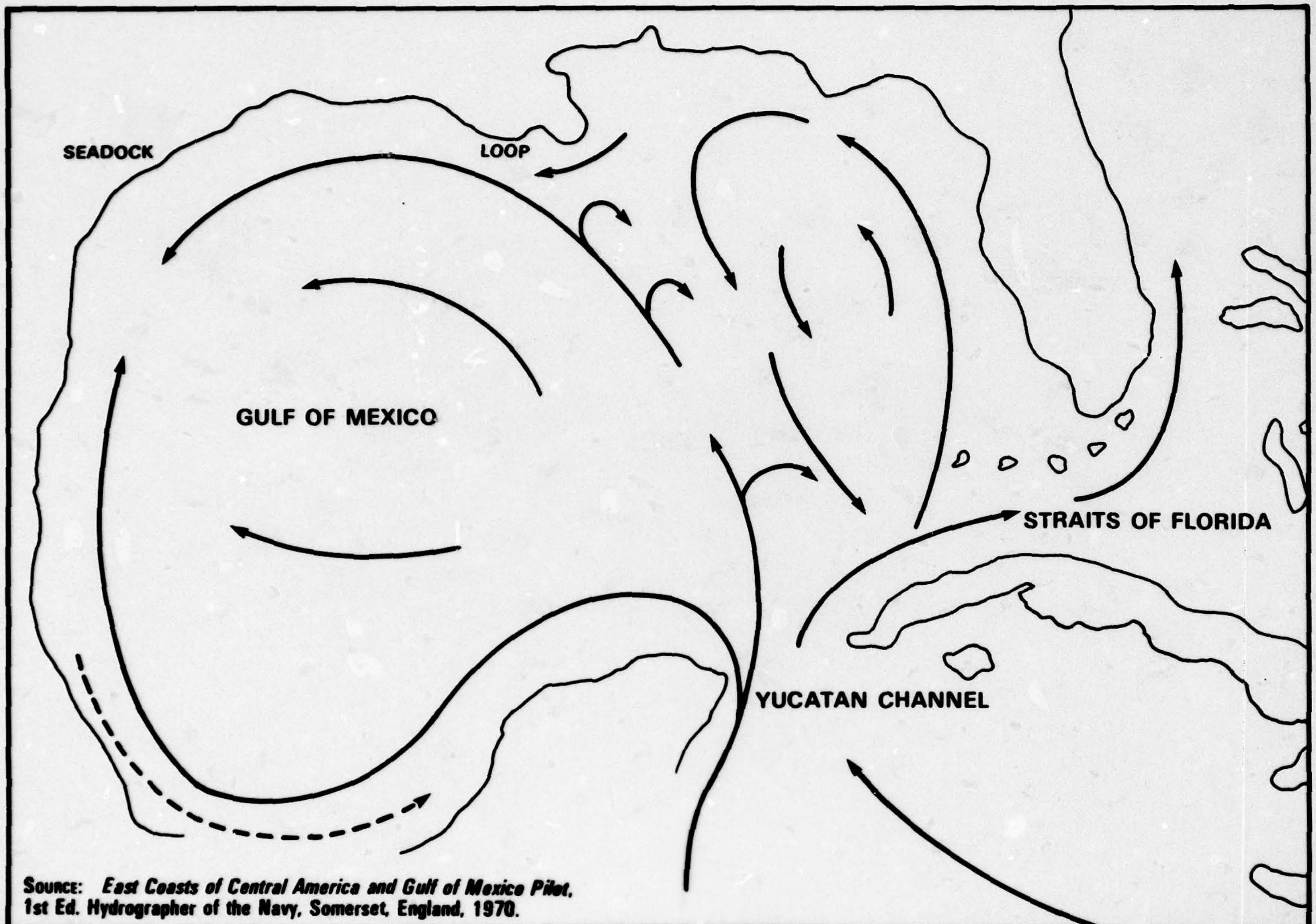
f. Florida Current

Although the Florida Current has its origins in the Yucatan Current, it does not actually take its name until it enters the Straits of Florida between Cuba and the Florida Keys. (See figures F-8 and F-9.) At this point, the current becomes very stable as it flows through the Straits following their contours. South of 25°N latitude, the mean speed is 2 knots with a maximum speed of 6 knots. North of 25°N latitude, the mean speed is 2.9 knots with a maximum speed of 6.5 knots. This flow prevails throughout the year with no change in direction; there are, however, slight variations in speed dependent upon the season. The faster speed, in general, occurs during the summer, and the slower speeds in the winter. Shortly after emerging from the Straits of Florida, the Florida Current is joined by the northwesterly flowing Antilles Current to form the Gulf Stream.



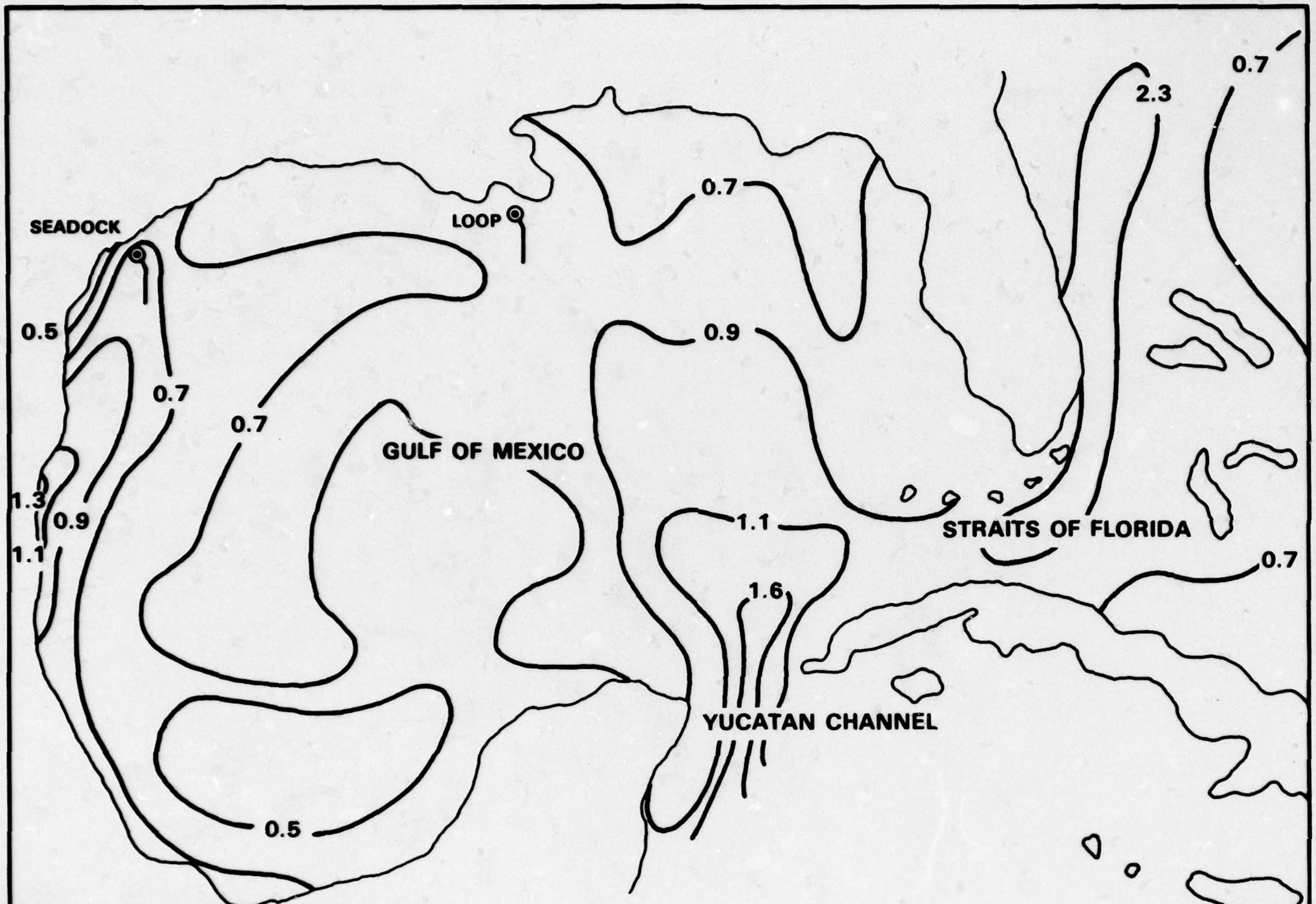
SOURCE: *East Coasts of Central America and Gulf of Mexico Pilot,* 1st Ed. Hydrographer of the Navy: Somerset, England, 1970.

FIGURE F-10. GENERAL SURFACE CURRENT CIRCULATION IN THE CARIBBEAN SEA AND GULF OF MEXICO THROUGHOUT THE YEAR



SOURCE: *East Coasts of Central America and Gulf of Mexico Pilot,* 1st Ed. Hydrographer of the Navy, Somerset, England, 1970.

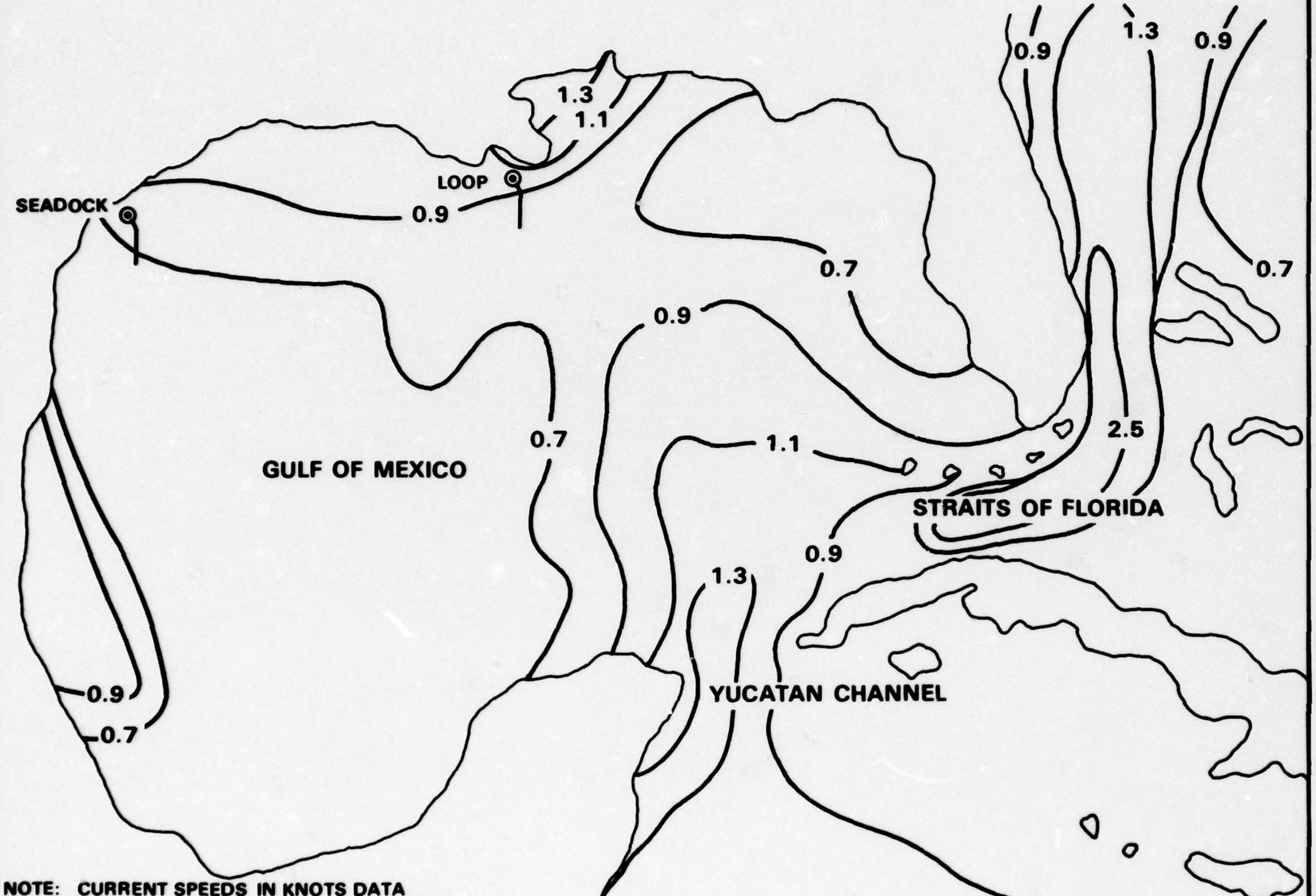
FIGURE F-11. GENERAL SURFACE CURRENT CIRCULATION IN THE GULF OF MEXICO THROUGHOUT THE YEAR



NOTE: CURRENT SPEEDS IN KNOTS DATA FOR MONTHS OF JULY, AUGUST, SEPTEMBER

SOURCE: *U.S. Navy Marine Climatic Atlas of the World.* Vol. I, U.S. Government Printing Office, Washington, D.C., 1971.

FIGURE F-12. MEAN SURFACE CURRENT SPEED DURING SUMMER



NOTE: CURRENT SPEEDS IN KNOTS DATA
FOR MONTHS OF JANUARY, FEBRUARY, MARCH

Source: *U.S. Navy Marine Climatic Atlas of the World,* Vol. 1. U.S. Government Printing Office, Washington, D.C., 1374.

FIGURE F-13. MEAN SURFACE CURRENT SPEED DURING WINTER

g. Gulf Stream

The union of the Florida Current and the Antilles Current produces a broad, deep current, with the same characteristics as the Florida Current with a reduced velocity and more lateral wandering. Some idea of the magnitude of the impetus of the Gulf Stream can be obtained by considering that the amount of flow out of the Straits of Florida is estimated to be more than 20 times the amount per hour of all fresh water that enters the oceans of the world from rivers, precipitation run off, and melting glaciers. The Gulf Stream continues in a northeasterly direction throughout the year with only minor changes in direction and velocity. The velocity is higher in summer than in winter by a slight amount. The Gulf Stream is a well defined current far beyond Cape Hatteras, however, from the Straits of Florida to that area velocities range from 1 to 3 knots.

h. Currents in the Area of LOOP

Figure F-11 shows the general surface current circulation in the Gulf of Mexico throughout the year. Figures F-12 and F-13 show that there is some slight seasonal variation in the speed of these currents. The average surface current flow in the area of LOOP is along the coastline in a northwesterly direction at speeds between 0.7 and 1 knot.[1] Changes in prevailing winds such as occur during storms can alter these currents to a marked degree.

i. Currents in the Area of SEADOCK

Figure F-11 shows the general surface current circulation in the Gulf of Mexico area throughout the year. Figures F-12 and F-13 show that there is some slight seasonal variation in the speed of these currents. The average surface current flow in the area of SEADOCK is west to southwest at speeds between 0.7 and 1 knot. Changes in prevailing winds such as occur during storm passage can alter these currents to a marked degree.

4. SUMMARY

As can be seen from the foregoing discussion of weather and currents, significant economic advantage can be realized from avoiding bad weather and utilizing routes which transit favorable currents. These advantages which are afforded by different routes are discussed in greater detail later in this report under chapter VI, "Hazard Identification and Ranking," however, some discussion should be included here concerning commercial services available to the mariner on a contin-

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1. National Oceanic and Atmospheric Administration, Environmental Guide for the U.S. Gulf Coast (Asheville, North Carolina: National Climatic Center, 1971), p. 72.

uing basis, which permit him to have his ocean route selected for him by means of dynamic computer programs. These programs project continuously his future position through forecast weather from beginning to end of his voyage. Continuous communication with the vessel is necessary in order to direct route alterations based on changing weather patterns. One of these companies advertises that vessels saved over 300 hours on a trans-Atlantic route over an unrouted ship of a similar type.[1] The U.S. Navy has used a similar system called "Optimum Track Ship Routing (OTSR)" for a number of years, which utiizes short range and extended range forecasting techniques in the route selection and enroute surveillance procedures. Short range forecasts of 3 to 5 days are computed from the meteorological primitive equations. These forecasts are computed twice a day from a data base of surface and upper air observations derived from many sources, including satellite surveillance. For the extended 3- to 14-day forecasts, there is a computer search of a library of weather history. In 1977, this library was based on 30 years of use.[2]

Whether or not a sophisticated system of weather routing is employed by a vessel on an ocean voyage in a tropical cyclone area, the safest procedure is to avoid these storms. If action is taken in sufficient time, this is merely a matter of steering a course which will avoid the storm, while keeping a constant track of the storm's movement. Sometimes, however, one finds himself unable for some reason to follow this course of action. The mariner may, for example, find himself in the Gulf of Mexico with a storm blocking his route to the open sea. In this case, minimizing the effect of the storm is the only alternative. Since tropical cyclones have a counterclockwise wind circulation in the Northern Hemisphere, that part to the right of the storm track as you face the direction toward which the storm is moving is known as the "dangerous semicircle." This is caused by the speed of the winds being augmented by the forward motion of the storm, and the direction of the wind tending to draw the vessel into the path of the storm. The part to the left of the storm, however, called the "navigable semicircle," has winds decreased by the speed of the storm movement and winds which tend to blow the vessel away from the storm track. Seas are also less severe in the navigable semicircle. Once caught in close proximity to a Northern Hemisphere tropical cyclone, the general rules to minimize its effects are:

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1. Ocean Routes, Inc. brochure "Oceanrouting for Safety, Timing, Economy." Palo Alto, California: Ocean Routes, Inc., 1978.
2. U.S. Defense Mapping Agency Hydrographic Center. American Practical Navigator. Publication No. 9. DMAHC: Washington, D.C., 1977, pp. 654, 655.

Right or dangerous semicircle -- bring the wind on the starboard bow, hold course and make as much speed as the weather permits. If required to heave to, keep ship's head into the sea.

Left or navigable semicircle -- bring the wind on the starboard quarter, hold course and make as much speed as the weather permits. If required to heave to, keep ship's stern to the sea.

On storm track ahead of center -- bring the wind on the starboard quarter, at about 160° relative, hold course and make as much speed as possible. When within the navigable semicircle, maneuver as described above.

On storm track behind center -- avoid the storm center by the best practical course, keeping in mind the general tendency of Northern Hemisphere tropical cyclones to curve northward and eastward, and the fact that their movements are frequently erratic.

Appendix G

CAUSES OF IMPACT CASUALTIES FROM THE VCRS DATA

In an attempt to statistically determine the chain of events which lead to a tanker casualty, the causal information from the VCRS data file has been analyzed. The impact casualty data from fiscal year 1970 through fiscal year 1977 for tankers greater than 5,000 gross tons were used. These data, shown in tables G-1, G-2 and G-3, include 243 collisions, 512 rammings, and 636 groundings.

The VCRS data system, since fiscal year 1970, has provided information on four causes of a casualty. These are labelled (1) primary cause, (2) primary factor, (3) area of causal connection, and (4) additional contributing factor. The primary cause is the general cause category (e.g., personnel fault) and the primary factor is a more specific delineation of the primary cause (e.g., rules-of-the-road violation, misjudged effects). Both the area of causal connection and the additional contributing factor are usually defined as contributing factors (e.g., unusual currents, low visibility). However, in some cases, the data entry in the *contributing factor field* is actually the effect of the casualty, that is, the part of the vessel that is damaged. Tables G-1, G-2, and G-3 do not list contributing factors in these instances. The coding scheme allows as many as six distinct violations to be recorded for rules-of-the-road violations, three in each of the third and fourth data fields (i.e., in area of causal connection and additional contributing factor). For example, entry I.A.4.a of table G-1 involves six recorded rules-of-the-road violations.

Tables G-1, G-2, and G-3 are presented in a form similar to an outline. The primary or general cause is preceded by a roman numeral, the specific cause is preceded by a capital letter and the first and second contributing factors are indicated respectively by arabic numbers and small letters. If the specific cause is "rules of the road," the first and second contributing factors very often show more than one rule violated. The rules violated are marked by "(i)," "(ii)," or "(iii)." There is no indication that any one of the violated rules listed was more responsible than the other two for the casualty. It should also be noted that there is no definitive indication that the first contributing factor was more responsible for the casualty than was the second factor. However, these factors are presented as they appeared in the VCRS data. Each listed cause is followed by a number which indicates the frequency of that cause. For example, 95 collisions were caused by personnel fault; of these 44 were a result of rule-of-the-road violation. Five of the 55 violations were

speed in fog/signal forward of beam. Excessive speed and radio telephone contributed to three of these five casualties.

The quantities for the subordinate elements may not add to the total for the superior next level for one of two reasons. First, as indicated above, a contributing factor entry is not listed if it is the part of the vessel which is damaged and is an effect rather than a cause of the casualty. Secondly, in many casualty reports, the subordinate elements were not given. That is, a primary cause may have been noted but no contributing factors or only one contributing factor indicated.

An attempt was made to determine from these data if any particular combinations of causes and contributing factors appeared with significant frequency to aid in the hazard ranking. While analysis of the relative frequencies of the various causes, particularly those related to personnel faults was useful in the hazard evaluation, we were not able to discern from these data significant combinations of causes and contributing factors that would aid further in evaluating hazards.

Table G-1

CAUSES OF COLLISIONS FROM VCRS DATA

I. PERSONNEL FAULT -- 95

A. Rule of Road -- 44

1. (i) Fog signals. (ii) Speed in fog/signal forward of beam. Early. (iii) Keep to starboard side of channel -- 1.

2. (i) Speed in fog/signal forward of beam. Early -- 5.

   a. (i) Excess speed. (ii) Radio telephone -- 3.

   b. Excessive speed -- 1.

3. (i) Speed in fog/signal forward of beam. Early. (ii) Improper lights -- 1.

4. (i) Speed in fog/signal forward of beam. Early. (ii) Fog signals. (iii) Rule of good seamanship (lookout) -- 1.

   a. (i) Excess speed. (ii) Failure to sound signals. (iii) Improper/no lookout -- 1.

5. (i) Fog signals. (ii) Keep to starboard side of channel. (iii) Rule of good seamanship (lookout) -- 1.

   a. (i) Excess speed. (ii) Wrong side of channel. (iii) Radio telephone -- 1.

6. (i) Speed in fog/signal forward of beam. Early. (ii) Rule of good seamanship (lookout) -- 5.

   a. (i) Excess speed. (ii) Evasive maneuver too little, too late. (iii) Radio telephone -- 2.

   b. (i) Excessive speed. (ii) Improper/no lookout -- 1.

   c. (i) Excessive speed. (ii) Radio telephone -- 1.

   d. (i) Failed to stop or back. (ii) Improper/no lookout. (iii) Excessive speed -- 1.

7. (i) Meeting situations -- 1.

   a. (i) Radio telephone -- 1.

8. (i) Meeting situations. (ii) Crossing situations. (iii) Burdened vessel avoid crossing ahead -- 1.

9. (i) Meeting situations. (ii) Keep to starboard side of channel -- 3.

   a. (i) Wrong side of channel. (ii) Radio Telephone --1.

   b. (i) Radio telephone. (ii) Evasive maneuver, too little, too late -- 1.

   c. (i) Excessive speed -- 1.

10. (i) Meeting situations. (ii) Keep to starboard side of channel. (iii) Rule of good seamanship (lookout) -- 1.

   a. (i) Wrong side of channel. (ii) Evasive maneuver, too little, too late -- 1.

11. (i) Meeting situations. (ii) General prudential rule -- 1.

12. (i) Danger signal -- 1.

   a. (i) Failure to sound signals. (ii) Radio telephone -- 1.

13. (i) Overtaking -- 1.

14. (i) Overtaking. (ii) Overtaking vessel keep clear -- 1.

   a. (i) Channels -- restricted maneuvering -- 1.

15. (i) Overtaking. (ii) Keep to starboard side of channel. (iii) Rule of good seamanship -- 1.

16. (i) Crossing situation -- 1.

   a. (i) Violation of law -- 1.

17. (i) Crossing situation. (ii) Burdened vessel avoid crossing ahead -- 2.

   a. (i) Lookout -- 1.

   b. (i) Failure to sound signals. (ii) Crossing situation, burdened, failed to give way. (iii) Evasive maneuver, too little, too late -- 1.

18. (i) Crossing situation. (ii) Burdened vessel keep clear --1.

19. (i) Crossing situation. (ii) Keep to starboard side of channel. (iii) Overtaking vessel keep clear -- 1.

20. (i) Crossing situation. (ii) General prudential rule. (iii) Danger signal -- 1.

   a. (i) Failure to sound signals. (ii) Evasive maneuver, too little, too late -- 1.

21. (i) Burdened vessel keep clear -- 1.

22. (i) Burdened vessel keep clear. (ii) Overtaking vessel keep clear -- 1.

23. (i) Burdened vessel keep clear. (ii) Rule of good seamanship (lookout) -- 1.

24. (i) Overtaking vessel keep clear -- 1.

    a. (i) Weather generally -- 1.

25. (i) Keep to starboard side of channel. (ii) Danger signal --1.

    a. (i) Radio telephone. (ii) Wrong side of channel --1.

26. (i) Right of way of fishing vessel -- 1.

27. (i) General prudential rule -- 1.

28. (i) General prudential rule. (ii) Rule of good seamanship (lookout) -- 2.

    a. -- Congested areas, docks, piers -- restricted maneuvering -- 1.

29. (i) Course signals international/backing inland. (ii) Failure to render assistance -- 1.

30. (i) Congested areas, docks, piers -- restricted maneuvering --1.

31. -- Radar -- 1.

B. Structural Failure -- Excessive Speed in Heavy Weather -- 4.

1. Poor visibility -- 3.

    a. Congested areas, docks, piers -- restricted maneuvering -- 1.

    b. Radar -- 1.

2. Radar -- 1.

    a. Weather generally -- 1.

C. Misjudged Effects -- Winds, Current, Speed -- 19.

1. Congested areas, docks, piers -- restricted maneuvering -- 2.

    a. Tug assisting -- 1.

2. Buoys, aids to navigation -- 1.

3. Excessive speed -- 2.

   a. Congested areas, docks, piers -- restricted maneuvering -- 1.

   b. Exterior communications: bridge/bridge radio --1.

4. Channels -- restricted maneuvering -- 2.

   a. Excessive speed -- 1.

   b. Currents and tides -- 1.

5. Weather generally -- 1.

   a. Congested areas, docks, piers -- restricted maneuvering -- 1.

6. Currents and tides -- 7.

   a. Congested areas, docks, piers -- restricted maneuvering -- 2.

   b. Poor visibility -- 1.

   c. Tug assisting -- 2.

D. Navigation -- Failed to Ascertain Position -- 2.

1. Poor visibility -- 2.

   a. Channels -- restricted maneuvering -- 1.

E. Navigation -- Failed to Utilize Available Navigation Equipment -- 1.

1. Poor visibility -- 1.

F. Maneuvered Without Proper Assistance -- 3.

1. Buoys, aids to navigation -- 1.

   a. Tug assisting -- 1.

2. Tug assisting -- 1.

   a. Congested areas, docks, piers -- restricted maneuvering -- 1.

G. Carelessness/Inattention (Asleep) -- 5.

1. Congested areas, docks, piers -- restricted maneuvering -- 1.

2. Channels -- restricted maneuvering -- 1.

a. Excessive speed -- 1.

3. Engine order telegraph, bell pulls, pilot house, engine controls -- 1.

a. Congested areas, docks, piers -- restricted maneuvering -- 1.

4. Violation of law -- 1.

H. Improper Corrective Procedures -- 5.

1. Congested areas, docks, piers -- restricted maneuvering -- 3.

a. Violation of law -- 1.

2. Channels -- restricted maneuvering -- 1.

a. Congested areas, docks, piers -- restricted maneuvering -- 1.

3. Radar -- 1.

I. Inadequate Control of Assisting Vessel -- 3.

1. Congested areas, docks, piers -- restricted maneuvering -- 1.

a. Tug assisting -- 1.

2. Excessive speed -- 1.

a. Tug assisting -- 1.

J. Improper Mooring/Towing -- 2.

1. Tug assisting -- 1.

2. Weather generally -- 1.

K. Improper Safety Precautions -- Loading Inflammable Liquid/Fueling/ Repairs -- 1.

1. Weather, generally -- 1.

a. Cargo -- 1.

L. Improper Securing/Rigging -- 2.

1. Congested areas, docks, piers -- restricted maneuvering -- 2.

a. Failure to secure -- 1.

M. Other -- Not Otherwise Classified -- 4.

1. Channels -- restricted maneuvering -- 3.

   a. Poor visibility -- 1.

2. Whistle, bell, horn, signals (improper use) -- 1.

   a. Channels -- restricted maneuvering -- 1.

II. ADVERSE WEATHER -- 13

A. Adverse Weather -- Restricted Visibility Only -- 1.

B. Large Swell as Across Bar -- 3.

C. Other -- 1.

D. Unexpected Gusty Wind, Docking/Undocking -- 3.

   1. Congested areas, docks, piers -- restricted maneuvering -- 1.

   2. Channels -- restricted maneuvering -- 1.

   3. Tug assisting -- 1.

E. Unknown -- 1.

F. Light Vessel Set Down on Pier/Lock -- 1.

   1. Weather generally -- 1.

      a. Congested areas, docks, piers -- restricted maneuvering -- 1.

G. Light Vessel Set Down on Moored Vessel -- 3.

   1. Congested areas, docks, piers -- restricted maneuvering -- 2.

   2. Weather generally -- 1.

III. UNUSUAL CURRENTS -- 3

A. Erratic -- 2.

   a. Congested areas, docks, piers -- restricted maneuvering -- 1.

      a. Tug assisting -- 1.

   2. Propellor -- 1.

      a. Tug assisting -- 1.

B. Strong Surge -- 1.

   1. Tug assisting -- 1.

IV. SHEER, SUCTION BANK CUSHION -- 3

A. Narrow Channel -- 2.

B. Other -- 1.

1. Channels -- restricted maneuvering -- 1.

V. RESTRICTED MANEUVERING ROOM -- NO PERSONNEL FAULT -- 3

A. No Otherwise Classified -- 3.

1. Channels -- restricted maneuvering -- 1.

2. Weather, generally -- 2.

VI. STRUCTURAL FAILURE -- NO PERSONNEL FAULT -- 3

A. Wasted Plates and Internals/Wood Rotted -- 1.

1. Tug assisting -- 1.

B. Indent -- Minor -- 2.

VII. EQUIPMENT FAILURE -- 7

A. Salt Water System -- 1.

B. Hydraulic Systems -- 1.

C. Electrical (All Equipment) -- 3.

1. Congested areas, docks, piers -- restricted maneuvering -- 1.

a. Currents and tides -- 1.

2. Navigational equipment: radar -- general -- 2.

a. Channels -- restricted maneuvering -- 1.

b. Poor visibility -- 1.

D. Deck Equipment -- Other (Anchor, Windlass, Chain, Mooring Line) -- 2.

1. Congested areas, docks, piers -- restricted maneuvering -- 1.

2. Winches: mooring lines -- general -- 1.

VIII. UNKNOWN/OTHER -- 2

A. Unknown -- 1.

B. Wake Damage From Other Vessel -- 1.

IX. FAULT OTHER VESSEL -- 112

A. Secondardy Cause Not Applicable -- 112.

1. Congested areas, docks, piers -- restricted maneuvering -- 1.

2. Channels -- restricted maneuvering -- 4.

3. Weather generally -- 1.

4. Currents and tides -- 1.

5. Background lighting obscured aids to navigation -- 1.

6. Ground tackle including anchor windlass -- 1.

7. Tug assisting -- 9.

8. Mooring equipment, lines, winches -- 1.

a. Channels -- restricted maneuvering -- 1.

9. Violation of law -- 3.

X. INSUFFICIENT HORSEPOWER/INADEQUATE TUG ASSISTANCE -- 2

A. No tugs available -- 1.

1. Channels -- restricted maneuvering -- 1.

a. Currents and tides -- 1.

B. Unable to Control Tow/Current -- 1.

1. Currents and tides -- 1.

Table G-2

CAUSES OF RAMMINGS FROM VCRS DATA

I. PERSONNEL FAULT -- 232

A. Rules of Road -- 3.

1. (i) Speed in fog/signal forward of beam. Early. (ii) Rule of good seamanship (lookout) -- 1.

a. (i) Excess speed. (ii) Evasive maneuver too little, too late. (iii) Radio telephone -- 1.

2. (i) Meeting situations. (ii) Failure to render assistance. (iii) Burdened vessel keep clear -- 1.

a. (i) Evasive maneuver, too little, too late. (ii) Radio telephone. (iii) Wrong side of channel -- 1.

3. (i) Rule of good seamanship (lookout) -- 1.

a. (i) Improper/no lookout -- 1.

B. Lookout - Improper/Failure to Post -- 2.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Excessive speed -- 1.

C. Structural Failure - Excessive Speed in Heavy Weather -- 1.

1. Congested areas, docks, piers - restricted maneuvering --1.

D. Misjudged Effects - Wind, Current, Speed -- 137.

1. Congested areas, docks, piers - restricted maneuvering --26.

a. Channels - restricted maneuvering -- 1.

b. Weather, generally -- 1.

c. Currents and tides -- 3.

d. Tug assisting -- 1.

2. Buoys, aids to navigation -- 1.

3. Excessive speed -- 23.

a. Congested areas, docks, piers - restricted maneuvering -- 11.

b. Channels - restrictive maneuvering -- 1.

c. Poor visibility -- 1.

d. Currents and tides -- 3.

e. Tug assisting -- 2.

4. Channels - restrictive maneuvering -- 7.

a. Congested areas, docks, piers - restricted maneuvering -- 2.

b. Weather, generally -- 1.

5. Poor visibility -- 1.

6. Weather, generally -- 15.

a. Congested areas, docks, piers - restricted maneuvering -- 5.

b. Buoys, aids to navigation -- 1.

c. Channels - restricted maneuvering -- 1.

d. Currents and tides -- 4.

7. Currents and tides -- 55.

a. Congested areas, docks, piers - restricted maneuvering -- 19.

b. Channels - restricted maneuvering -- 2.

c. Weather, generally -- 13.

d. Tug assisting -- 6.

e. Mooring equipment, lines, winches -- 1.

f. Failure of electrical equipment due to improper or lack of maintenance -- 1.

8. Tug assisting -- 1.

9. Violation of law -- 1.

E. Navigation - Failed to Ascertain Position -- 7.

1. Congested areas, docks, piers - restricted maneuvering --4.

2. Excessive speed -- 1.

3. Channels - restricted maneuvering -- 1.

4. Currents and tides -- 1.

F. Navigation - Failed to Utilize All Available Navigation Equipment -1.

G. Vessel Sheered/Agreement Reached -- 2.

1. Congested areas, docks, piers - restricted maneuvering --2.

a. Tug assisting -- 2.

H. Failure to Properly Align Tow -- 2.

1. Congested areas, docks, piers - restricted maneuvering --2.

I. Lack of Local Knowledge -- 2.

1. Congested areas, docks, piers - restricted maneuvering --2.

J. Inexperienced Personnel -- 1.

K. Maneuvered Without Proper Assistance -- 13.

1. Congested areas, docks, piers - restricted maneuvering --3.

a. Currents and tides -- 1.

2. Poor visibility -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Weather, generally -- 2.

a. Tug assisting -- 1.

4. Currents and tides -- 5.

a. Congested areas, piers, docks - restricted maneuvering -- 3.

L. Carelessness/Inattention (Asleep) -- 8.

1. Congested areas, piers, docks - restricted maneuvering --3.

a. Tug assisting -- 1.

2. Channels - restricted maneuvering -- 1.

3. Steering gear including steering engine, rudder, auto pilot -- 1.

a. Channels - restricted maneuvering -- 1.

4. Tug assisting -- 1.

    a. Congested areas, docks, piers - restricted maneuvering -- 1.

M. Improper Corrective Procedures -- 7.

1. Congested areas, docks, piers - restricted maneuvering --2.

2. Excessive speed -- 3.

    a. Congested areas, docks, piers - restricted maneuvering -- 2.

3. Failure of equipment due to improper or lack of maintenance -- 1.

N. Poor Seamanship - Fouled Wheel/Shaft -- 2.

1. Congested areas, docks, piers - restricted maneuvering --1.

O. Failed - Improperly Determined Height of Tide; Failed to Correct --3.

1. Congested areas, docks, piers - restricted maneuvering --1.

    a. Tug assisting -- 1.

2. Currents and tides -- 2.

    a. Congested areas, docks, piers - restricted maneuvering -- 1.

P. Inadequate Control of Assisting Vessel -- 18.

1. Congested areas, docks, piers - restricted maneuvering --5.

    a. Currents and tides -- 1.

    b. Tug assisting -- 2.

2. Buoys, aids to navigation -- 1.

    a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Excessive speed -- 1.

    a. Tug assisting -- 1.

4. Steering gear including steering engine, rudder, auto pilot -- 1.

    a. Tug assisting -- 1.

5. Currents and tides -- 3.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

6. Radiotelephone failed to use/improper use -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

7. Tug assisting -- 6.

a. Congested areas, docks, piers - restricted maneuvering -- 4.

b. Bridge/bridge radio -- 2.

Q. Improper Mooring/Towing (Tripping) -- 7

1. Congested areas, docks,piers - restricted maneuvering --4.

a. Excessive speed -- 1.

2. Currents and tides -- 1.

R. Other, Not Otherwise Classified -- 16.

1. Congested areas, docks, piers - restricted maneuvering --7.

a. Weather, generally -- 2.

2. Excessive speed -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Currents and tides -- 1.

4. Exterior communications: bridge/bridge radio -- 1.

II. ADVERSE WEATHER (INCLUDING STORMS, HEAVY WEATHER) -- 51

A. Typhoon, Hurricane, Etc. -- 2.

1. Ground tackle including anchor windlass -- 2.

a. Weather, generally -- 1.

B. Gale Force Winds -- 5.

1. Congested areas, docks, piers - restricted maneuvering --4.

2. Ground tackle including anchor windlass -- 1.

C. Adverse Weather - Restricted Visibility Only -- 4.

1. Channels - restricted maneuvering -- 4.

a. Poor visibility -- 1.

b. Currents and tides -- 1.

D. Winds, Small Craft - Gale Force -- 2.

1. Channels - restricted maneuvering -- 1.

a. Congested area, docks, piers - restricted maneuvering -- 1.

E. Large Swell - As Across Bar -- 1.

1. Currents and tides -- 1.

F. Anchor Failed To Hold/Drifted -- 8.

1. Lookout -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Congested areas, docks, piers - restricted maneuvering --1.

3. Weather, generally -- 1.

4. Currents and tides -- 4.

G. Unexpected Gusty Wind, Docking/Undocking -- 10.

1. Congested areas, docks, piers - restricted maneuvering --7.

a. Tug assisting -- 2.

2. Ground tackle including anchor windlass -- 1.

a. Congested areas, piers, docks - restricted maneuvering -- 1.

3. Tug assisting -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

H. Tow/Mooring Part Due Heavy Weather -- 5.

1. Replenishment at sea -- 1.

2. Mooring equipment, lines, winches -- 1.

I. Squalls - Reduced Visibility/Wind -- 1.

J. Anchor Parted -- 1.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

K. Light Vessel Set Down on Pier/Lock -- 3.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Weather, generally - 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Ground tackle including anchor windlass - 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

L. Ice -- 9.

1. Weather, generally -- 1.

III. UNUSUAL CURRENTS -- 10

A. Erratic -- 2.

1. Congested areas, docks, piers - restricted maneuvering -- 2.

a. Currents and tides -- 2.

B. Strong Currents/Narrow Channel -- 6.

1. Congested areas, docks, piers - restricted maneuvering -- 2.

2. Channels - restricted maneuvering -- 1.

3. Currents and tides -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

C. Strong Surge -- 1.

1. Current and tides -- 1.

D. Other -- 1.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

IV. SHEER, SUCTION, BANK CUSHION -- 5

A. Narrow Channel -- 2.

1. Channels - restricted maneuvering -- 1.

B. Navigating Close to Shore -- 2.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 1.

C. Other -- 1.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

V. DEPTH LESS THAN CHARTED -- 2

A. Area Shoalled/Silted -- 2.

1. Congested areas, piers, docks - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 1.

VI. RESTRICTED MANEUVERING ROOM - NO PERSONNEL FAULT -- 17

A. Not Otherwise Classified -- 17.

1. Lookout -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Congested areas, docks, piers - restricted maneuvering -- 5.

a. Channels - restricted maneuvering -- 1.

b. Tug assisting -- 1.

3. Buoys, aids to navigation -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

4. Channels - restricted maneuvering -- 1.

5. Poor visibility -- 1.

6. Tug assisting -- 2.

VII. STRUCTURAL FAILURE - NO PERSONNEL FAULT -- 10

A. Fracture - Plates and Internals -- 6.

1. Hull - external - forword 1/3 - side show -- 4.

a. Anchor/vessel anchored -- 4.

2. Hull - external - midshipsection - sideshow -- 1.

a. Anchor/vessel anchored -- 1.

3. Hull - external - aft 1/3 -- 1.

a. Mooring lines - general -- 1.

B. Indent - Minor -- 1.

1. Hull - external - midshipsection - sideshow -- 1.

a. Mooring lines - general -- 1.

C. Set Up - Major -- 1.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Hull - general -- 1.

D. Buckling -- 1.

1. Congested areas, docks,piers - restricted maneuvering --1.

E. Other -- 1.

VIII. EQUIPMENT FAILURE -- 27

A. Main Steam System -- 1.

1. Hull - general -- 1.

B. Feed and Condensate System -- 1.

1. Tug assisting -- 1.

a. Channels - restricted maneuvering -- 1.

C. Fresh Water System - (Excluding Feed System) -- 1.

1. Congested areas, docks, piers - restricted maneuvering --1.

a. Currents and tides -- 1.

D. Fuel Oil Service System -- 1.

1. Main Propulsion Diesel Engine -- 1.

E. Fuel Oil Transfer System -- 1.

1. Excessive speed -- 1.

F. Lube Oil System -- 1.

1. Currents and tides -- 1.

a. Winches: anchor/vessel anchored -- 1.

G. Hydraulic Systems -- 1.

1. Tug assisting -- 1.

a. Currents and tides -- 1.

H. Pneumatic System -- 1.

1. Controllable Pitch Propellors General -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

I. Ventilation System -- 3.

1. Steam turbine and turboelectric -- 1.

a. Channels - restricted maneuvering -- 1.

2. Miscellaneous machinery - not otherwise classified -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Generators (except main propulsion) -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

J. Sanitary System and Hull Drainage System (Including Bilge System) --1.

1. Mooring equipment, lines, winches -- 1.

a. Currents and tides -- 1.

K. Electrical (All Equipment) -- 7.

1. Steering gear - general -- 4.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

b. Poor visibility -- 1.

2. Electrical: main generator -- 2.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Interior communications: engine order telegraph -- 1.

a. Throttle control equipment -- 1.

L. Deck Equipment - Other (Anchor Windlass, Chain, Mooring Line) -- 3.

1. Winches: anchor windlass - general -- 1.

a. Failure of equipment due to improper or lack of maintenance -- 1.

2. Winches: natural fiber -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

3. Winches: towing cable -- 1.

a. Hull: fracture - other -- 1.

M. Other -- 5.

1. Steering gear: general -- 1.

a. Hull: general -- 1.

2. Main propulsion diesel engine -- 4.

a. Currents and tides -- 1.

b. Hull - general -- 2.

c. Hull - indent - minor -- 4.

IX. IMPROPER MAINTENANCE -- 1

A. Failure of Wood Hull Plating/Moderate Seas -- 1.

1. Propellers - solid -- 1.

X. UNKNOWN/OTHER -- 11

A. Dock Bollard Failure -- 2.

1. Weather, generally -- 2.

a. Hull - general -- 1.

B. Unknown -- 1.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Hull - general -- 1.

C. Wake Damage From Other Vessel -- 2.

1. Winches: mooring lines - general -- 2.

D. Other -- 6.

1. Buoys, aids to navigation -- 1.

2. Channels - restricted maneuvering -- 1.

3. Tug assisting -- 1.

4. Hull - general -- 1.

5. Hull - external - forward 1/3 - sideshow -- 1.

XI. FAULT OTHER VESSEL/PERSONNEL -- 80

A. Not Otherwise Classified -- 75.

1. Congested areas, docks, piers - restricted maneuvering --1.

2. Buoys, aids to navigation -- 1.

a. Channels - restricted maneuvering -- 1.

3. Excessive speed -- 1.

4. Channels - restricted maneuvering -- 1.

a. (i) Crossing situation, burdened failed to give way. (ii) Improper lights/shapes -- 1.

5. Ground tackle including anchor windlass -- 8.

6. Tug assisting -- 3.

7. Mooring equipment, lines,winches -- 4.

8. Weather, generally -- 1.

B. Vessel Intentionally Grounded To Avoid Collision -- 1.

1. Channels - restricted maneuvering -- 1.

C. Bridge Tender Closed Drawbridge -- 1.

1. Whistle, bell, horn, signals (improper use) -- 4.

a. Ground tackle including anchor windlass -- 1.

D. Other -- 3.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Tug assisting -- 1.

2. Buoys, aids to navigation -- 1.

3. Tug assisting -- 1.

XII. FLOATING DEBRIS, SUBMERGED OBJECT (OTHER THAN BOTTOM) -- 60

A. Submerged Object -- 50.

1. Congested areas, docks, piers - restricted maneuvering -- 3.

a. Propeller -- 1.

2. Channels - restricted maneuvering -- 5.

3. Sunken wreck -- 1.

4. Propeller -- 13.

a. Channels - restricted maneuvering -- 2.

b. Weather, generally -- 1.

c. Shafts and reduction gears -- 2.

B. Wooden Hull Holed -- 1.

C. Damaged -- 9.

1. Propeller -- 3.

a. Weather, generally -- 1.

XIII. INSUFFICIENT HORSEPOWER/INADEQUATE TUG ASSISTANCE -- 6

A. No Tugs Available -- 2.

1. Buoys, aids to navigation -- 1.

a. Channels - restricted maneuvering -- 1.

2. Currents and tides -- 1.

B. Not Enough Tugs Ordered -- 2.

1. Congested areas, docks, piers - restricted maneuvering -- 2.

a. Violation of law -- 1.

C. Unable To Control Light Tow/Wind -- 1.

1. Tug assisting -- 1.

D. Unable To Control Tow/Current -- 1.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Currents and tides -- 1.

Table G-3

CAUSES FOR TANKER GROUNDINGS FROM VCRS DATA

I. PERSONNEL FAULT -- 323

   A. Structural Failure - Improper Loading -- 1.

   B. Structural Failure - Excessive Speed in Heavy Weather -- 1.

      1. Channels - restricted maneuvering -- 1.

   C. Misjudged Effects -- 129.

      1. Lookout -- 1.

      2. Congested areas, docks, piers - restricted maneuvering -- 5.

         a. Channels - restricted maneuvering -- 1.

      3. Buoys, aids to navigation -- 2.

         a. Currents and tides -- 2.

      4. Excessive speed -- 5.

         a. Congested areas, piers, docks - restricted maneuvering -- 1.

         b. Channels - restricted maneuvering -- 2.

         c. Currents and tides -- 1.

      5. Channels - restricted maneuvering -- 31.

         a. Poor visibility -- 1.

         b. Weather, generally -- 4.

         c. Currents and tides -- 2.

         d. Cargo -- 1.

         e. Tug assisting -- 1.

      6. Poor visibility -- 3.

         a. Channels - restricted maneuvering -- 1.

         b. Currents and tides -- 2.

7. Weather, generally -- 6.

    a. Channels - restricted maneuvering -- 2.

    b. Currents and tides -- 1.

8. Currents and tides -- 70.

    a. Congested areas, docks, piers - restricted maneuvering -- 12.

    b. Channels - restricted maneuvering -- 19.

    c. Poor visibility -- 2.

    d. Weather, generally -- 7.

    e. Tug assisting -- 2.

9. Disabled, require tow -- 1.

10. Tug assisting -- 1.

    a. Currents and tides -- 1.

D. Navigation - Reliance on Floating Aids to Navigation -- 8.

1. Channels - restricted maneuvering -- 3.

    a. Buoys, aids to navigation -- 1.

2. Poor visibility -- 2.

    a. Radar -- 2.

3. Weather, generally -- 3.

    a. Buoys, aids to navigation -- 1.

    b. Channels - restricted maneuvering -- 1.

E. Navigation - Failed to Ascertain Position -- 75.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Buoys, aids to navigation -- 6.

    a. Excessive speed -- 1.

3. Excessive speed -- 1.

    a. Poor visibility -- 1.

4. Channels - restricted maneuvering -- 29.

    a. Congested areas, docks, piers - restricted maneuvering -- 2.

    b. Buoys, aids to navigation -- 2.

    c. Poor visibility -- 1.

    d. Radar -- 1.

    e. Currents and tides -- 6.

    f. Tug assisting -- 1.

5. Poor visibility -- 11.

    a. Channels - restricted maneuvering -- 6.

    b. Radar -- 2.

6. Radar -- 1.

    a. Poor visibility -- 1.

7. Navigation equipment - NOC -- 2.

8. Weather, generally -- 2.

9. Currents and tides -- 2.

    a. Channels - restricted maneuvering -- 1.

    b. Ground tackle including anchor windlass -- 1.

10. Overloading -- 1.

11. Rudder angle indicator system -- 1.

    a. Channels - restricted maneuvering -- 1.

12. Gyro compass system -- 1.

    a. Channels - restricted maneuvering -- 1.

13. Buoys, aids to navigation -- 1.

F. Navigation - Failed To Utilize All Available Navigation Equipment --12.

1. Congested areas, docks, piers - restricted maneuvering --1.

2. Buoys, aids to navigation -- 1.

3. Channels - restricted maneuvering -- 2.

   a. Poor visibility -- 1.

4. Poor visibility -- 1.

   a. Violation of law -- 1.

5. Radar - general -- 1.

   a. Poor visibility -- 1.

6. Violation of law -- 1.

G. Vessel Sheered/Agreement Reached -- 2.

1. Channels - restricted maneuvering -- 1.

2. Currents and tides -- 1.

H. Lack of Local Knowledge -- 4.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 3.

I. Maneuvered Without Proper Assistance -- 11.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 2.

3. Currents and tides -- 6.

   a. Congested areas, docks, piers - restricted maneuvering -- 2.

   b. Channels - restricted maneuvering -- 1.

   c. Tug assisting -- 2.

4. Tug assisting -- 1.

   a. Currents and tides -- 1.

J. Carelessness/Inattention (Asleep) -- 14.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 6.

   a. Buoys, aids to navigation -- 1.

   b. Tug assisting -- 1.

3. Currents and tides -- 1.

   a. Congested areas, docks, piers - restricted maneuvering -- 1.

4. Improper loading or stowage -- 1.

5. Anchor/vessel anchored -- 1.

   a. Congested areas, docks, piers - restricted maneuvering -- 1.

6. Maneuvering valves -- 1.

   a. Tug assisting -- 1.

K. Improper Corrective Procedures -- 9.

1. Congested areas, docks, piers - restricted maneuvering --2.

   a. Channels - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 2.

   a. Currents and tides -- 1.

3. Poor visibility -- 2.

   a. Channels - restricted maneuvering -- 1.

4. Ground tackle including windlass -- 2.

   a. Weather, generally -- 2.

L. Poor Seamanship - Fouled Wheel/Shaft -- 4.

1. Ground tackle including anchor windlass -- 1.

M. Failed - Improperly Determined Height Of Tide; Failed To Correct --27.

1. Congested areas, docks, piers - restricted maneuvering -- 4.

   a. Weather, generally -- 1.

   b. Currents and tides -- 1.

   c. Tug assisting -- 1.

2. Currents and tides -- 10.

   a. Congested areas, docks, piers - restricted maneuvering -- 1.

b. Channels - restricted maneuvering -- 3.

c. Weather, generally -- 1.

d. Ground tackle including anchor windlass -- 1.

e. Tug assisting -- 1.

f. Mooring equipment, lines, winches -- 1.

3. Channels - restricted maneuvering -- 8.

a. Currents and tides -- 4.

b. Ground tackle including anchor windlass -- 1.

c. Tug assisting -- 2.

4. Overloading -- 1.

5. (Charts failed to use), other -- 1.

a. Tug assisting -- 1.

N. Inadequate Control Of Assisting Vessel -- 4.

1. Channels - restricted maneuvering -- 1.

2. Currents and tides -- 2.

a. Channels - restricted maneuvering -- 1.

3. Congested areas, piers, docks - restricted maneuvering -- 1.

O. Improper Mooring/Towing (Tripping) -- 8.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Violation of law -- 1.

2. Mooring equipment, lines, winches -- 1.

a. Currents and tides -- 1.

3. Currents and tides -- 4.

P. Improper Safety Precautions - Loading Inflammable Liquid/Fueling/ Repairs -- 1.

1. Improper loading or stowage -- 1.

Q. Improper Securing/Rigging -- 1.

1. Overloading -- 1.

R. Other, Not Otherwise Classified -- 13.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Buoys, aids to navigation -- 1.

a. Background lighting obscured aids to navigation -- 1.

3. Excessive speed -- 1.

a. Channels - restricted maneuvering -- 1.

4. Channels - restricted maneuvering -- 5.

a. Poor visibility -- 1.

b. Violation of law -- 1.

5. Currents and tides -- 1.

a. Ground tackle including windlass -- 1.

II. ADVERSE WEATHER -- 38

A. Typhoon, Hurricane, Etc. -- 2.

1. Channels - restricted maneuvering -- 1.

2. Mooring equipment, lines, winches -- 1.

B. Adverse Weather - Restricted Visibility Only -- 5.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 1.

3. Poor visibility -- 1.

4. Radar -- 2.

a. Buoys, aids to navigation -- 1.

C. Small Craft Warnings -- 1.

D. Winds, Small Craft - Gale Force -- 2.

1. Currents and tides -- 1.

E. Anchor Failed To Hold/Drifted -- 16.

1. Congested areas, docks, piers - restricted maneuvering -- 2.

2. Channels - restricted maneuvering -- 1.

3. Poor visibility -- 1.

a. Currents and tides -- 1.

4. Weather, generally -- 3.

a. Channels - restricted maneuvering -- 1.

b. Currents and tides -- 1.

5. Currents and tides -- 6.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

b. Channels - restricted maneuvering -- 1.

6. Failure to secure (or improper) -- 1.

F. Other -- 1.

1. Currents and tides -- 1.

a. Weather, generally -- 1.

G. Unexpected Gusty Wind, Docking/Undocking -- 2.

1. Weather, generally -- 1.

H. Tow/Mooring Part Due Heavy Weather -- 2.

1. Currents and tides -- 1.

2. Weather, generally -- 1.

I. Squalls - Reduced Visibility, Wind -- 1.

1. Channels - restricted maneuvering -- 1.

J. Light Vessel Set Down On Pier/Lock -- 3.

1. Channels - restricted maneuvering -- 1.

a. Weather, generally -- 1.

2. Poor visibility -- 1.

a. Weather, generally -- 1.

3. Weather, generally -- 1.

a. Channels - restricted maneuvering -- 1.

K. Ice -- 3.

1. Channels - restricted maneuvering -- 1.

III. UNUSUAL CURRENTS -- 4

A. Strong Currents/Narrow Channel -- 3.

1. Channels - restricted maneuvering -- 2.

a. Currents and tides -- 2.

B. Other -- 1.

1. Channels - restricted maneuvering -- 1.

IV. SHEER, SUCTION, BANK CUSHION -- 23

A. Narrow Channel -- 16.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Channels - restricted maneuvering -- 10.

a. Buoys, aids to navigation -- 1.

3. Currents and tides -- 2.

B. Navigating Close To Shore -- 6.

1. Excessive speed -- 1.

2. Channels - restricted maneuvering -- 5.

C. Other -- 1.

1. Channels - restricted maneuvering -- 1.

a. Tug assisting -- 1.

V. DEPTH LESS THAN CHARTED -- 140

A. Charts Erroneous -- 5.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

B. Area Shoalled/Silted -- 130.

1. Congested areas, docks, piers - restricted maneuvering -- 6.

2. Buoys, aids to navigation -- 1.

3. Channels - restricted maneuvering -- 74.

a. Weather, generally -- 1.

b. Currents and tides -- 2.

c. Tug assisting -- 1.

4. Weather, generally -- 7.

5. Currents and tides -- 2.

a. Congested areas, piers, docks - restricted maneuvering -- 1.

6. Background lighting obscured aids to navigation --1.

C. Position Of Hazard Doubtful -- 4.

1. Channels - restricted maneuvering -- 2.

D. Other -- 1.

1. Buoys, aids to navigation -- 1.

VI. RESTRICTED MANEUVERING ROOM - NO PERSONNEL FAULT -- 8

A. Not Otherwise Classified -- 8.

1. Congested areas, docks, piers - restricted maneuvering -- 2.

a. Tug assisting -- 1.

2. Channels - restricted maneuvering -- 3.

3. Weather, generally -- 1.

4. Currents and tides -- 1.

5. Ground tackle including windlass -- 1.

VII. STRUCTURAL FAILURE - NO PERSONNEL FAULT -- 3

A. Wasted Welds -- 1.

1. Channels - restricted maneuvering -- 1.

B. Fracture - Plates and Internals -- 1.

1. Hull - external - forward 1/3 - bottom -- 1.

a. Hull - internals - forward 1/3 -- 1.

C. Set Up - Major -- 1.

1. Hull - external - forward 1/3 - bottom -- 1.

a. Hull - internals - forward 1/3 -- 1.

VIII. EQUIPMENT FAILURE -- 51

A. Main Steam System -- 1.

B. Salt Water System -- 1.

1. Channels - restricted maneuvering -- 1.

C. Fuel Oil Transfer System -- 4.

1. Steering gear including steering engine, rudder, auto pilot -- 4.

a. Channels - restricted maneuvering -- 3.

D. Lube Oil System -- 1.

1. Diesel engine and accessories -- 1.

a. Currents and tides -- 1.

E. Hydraulic Systems -- 4.

1. Channels - restricted maneuvering -- 1.

a. Steering gear - general -- 1.

2. Hydraulic system -- 1.

a. Channels - restricted maneuvering -- 1.

3. Pumps -- 1.

4. Shafting and bearings -- 1.

F. Ventilation System -- 4.

1. Tug assisting -- 1.

a. Currents and tides -- 1.

2. Diesel engine and accessories -- 1.

a. Channels - restricted maneuvering -- 1.

3. Steam turbine and turboelectric -- 1.

a. Steering gear, including steering engine, rudder, auto pilot -- 1.

4. Feedwater systems including condensers and evaporators -- 1.

a. Steam turbine and turboelectric -- 1.

G. Sanitary System and Hull Drainage System (Including Bilge System) -- 1.

1. Ground tackle including anchor windlass -- 1.

a. Currents and tides -- 1.

H. Electrical (All Equipment) -- 8.

1. Channels - restricted maneuvering -- 1.

2. Main propulsion -- 1.

a. Channels - restricted maneuvering -- 1.

3. Main propulsion diesel reduction -- 1.

4. Ship's service diesel generator - engine - engine (excluding accessories) governing system -- 1.

a. Rudder - general -- 1.

5. Ship's service diesel generator -- 1.

a. Channels - restricted maneuvering -- 1.

6. Ships' service generator turbines - general -- 1.

7. Ship's service generator switchboard -- 1.

8. Radar - general -- 1.

a. Gyro compass system -- 1.

I. Other -- 27.

1. Winches: anchor windlass - general -- 1.

2. Steering gear: general -- 15.

a. Channels - restricted maneuvering -- 1.

b. Hull - general -- 1.

c. Hull - external - forward 1/3 - bottom -- 1.

d. Steering gear: follow-up mechanism (linkages) - 1.

e. Main propulsion diesel engine -- 1.

3. Steering gear: cross head and cross head drive --1.

a. Channels - restricted maneuvering -- 1.

4. Steering gear: hydraulic system -- 2.

   a. Piping -- 1.

5. Steering gear: pumps -- 2.

   a. Auxiliary system turbines and gears: governing system -- 1.

   b. Hull - general -- 1.

6. Steering gear: rudder - general -- 2.

7. Main propulsion diesel engine -- 2.

   a. Steering generator: rudder - general -- 1.

8. Main propulsion turbines - general (H.P. and L.P.) -- 1.

   a. Hull - general -- 1.

9. Navigation equipment - gyro compass system -- 1.

   a. Poor visibility -- 1.

IX UNSEAWORTHY -- 1

A. Steel Hull Deteriorated -- 1.

1. Built-in tanks - ballast -- 1.

X. UNKNOWN/OTHER -- 12

A. Unknown -- 7.

1. Buoys, aids to navigation -- 1.

   a. Radar - general -- 1.

2. Channels - restricted maneuvering -- 1.

3. Currents and tides -- 1.

   a. Anchor/vessel anchored -- 1.

4. Hull - general -- 1.

   a. Fracture - other -- 1.

5. Hull - external - forward 1/3 - side show -- 1.

   a. Indent - Minor -- 1.

6. Hull - Indent - Minor -- 1.

B. Other - 5.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

2. Buoys, aids to navigation -- 2.

a. Channels - restricted maneuvering -- 1.

3. Channels - restricted maneuvering -- 1.

4. Main propulsion diesel engine -- 1.

XI. FAULT OTHER VESSEL/PERSONNEL -- 21

A. Not Otherwise Classified -- 5.

1. Tug assisting -- 1.

B. Vessel Intentionally Grounded to Avoid Collision -- 14.

1. Congested areas, docks, piers - restricted maneuvering -- 2.

2. Channels - restricted maneuvering -- 8.

a. Currents and tides -- 1.

3. Currents and tides -- 2.

a. Channels - restricted maneuvering -- 1.

b. Poor visibility -- 1.

4. Propeller -- 1.

a. Currents and tides -- 1.

C. Bridge Tender Failed To Fully Open Span -- 1.

D. Other -- 1.

1. Channels - restricted maneuvering -- 1.

XII. FLOATING DEBRIS, SUBMERGED OBJECT (OTHER THAN BOTTOM) -- 7

A. Submerged Object -- 6.

1. Channels - restricted maneuvering -- 2.

2. Sunken wreck -- 1.

B. Damaged -- 1

1. Violation of law -- 1.

a. Congested areas, docks, piers - restricted maneuvering -- 1.

XIII. INSUFFICIENT HORSEPOWER/INADEQUATE TUG ASSISTANCE -- 5

A. No Tugs Available -- 4.

1. Congested areas, docks, piers - restricted maneuvering -- 1.

a. Buoys, aids to navigation -- 1.

2. Weather, generally -- 1.

a. Channels - restricted maneuvering -- 1.

3. Currents and tides -- 2.

B. Not Enough Tugs Ordered -- 1.

1. Channels - restricted maneuvering -- 1.

a. Weather, generally -- 1.

APPENDIX H
DELINEATION OF PERSONNEL FAULTS

Personnel fault is clearly one of the most important factors in tanker casualties being indicated as a primary cause in 29 of the 97 casualties (30 percent) analyzed for the hazard rating by zone of table VI-2 and 39 of the 148 Gulf casualties (25 percent) listed in table VI-4. The 29 casualties involving personnel fault are categorized further in table H-1 below. However, this data set provides a limited data base with which to analyze personnel faults. Because personnel fault is indicated in a large proportion of vessel casualties, a further delineation and discussion of the types and underlying causes of personnel factors is provided herein.

A summary of types of personnel faults by casualty type is presented in table H-2 for all casualties involving tankers greater than 5,000 GT over the period FY 1970-77 based upon VCRS data. In these data, collisions are included if at least one vessel is a tanker larger than 5,000 GT. In collision cases in which both are tankers larger than 5,000 GT, only the primary vessel (vessel at fault) data are included. If one of the vessels is not a tanker or is a tanker less than 5,000 GT and it is judged at fault, the cause is denoted as "fault or other vessel/personnel." This cause is also ascribed in cases where another vessel's movements may cause the tanker to go aground or ram an object in attempting to avoid a collision.

The primary types of personnel faults for collisions are rules-of-the-road violations (52 percent) and misjudged effects (22 percent). For rammings the primary factor is misjudged effects (55 percent). The primary causal types for groundings are misjudged effects (48 percent), failure to ascertain position (28 percent) and improperly determined height of tide (10 percent). Additional information on the frequencies of the various factors and their combinations are given in appendix G.

Two of the most frequently cited faults--misjudged effects and rules-of-the-road violations--are also those with the highest frequency in the surrogate data of table VI-1. Failure to ascertain position is relatively less frequently cited in the surrogate data than in the data of table H-2 because groundings, where this fault is prevalent, have been deleted from entrances and harbors in the surrogate data.

While these categorizations are useful, they do not provide information on the causal factors leading to the personnel fault that can possibly be mitigated by such measures as training, licensing, etc.

Table H-1 Personnel Fault Categories for DWP Surrogates

		Number of Times Cited
Coastal (Straits and Channels)		7
Rules of the Road	3	
Improper Corrective Procedures	1	
Other	3	
Open Sea (Open Gulf)		0
Harbor Entrances (Safety Fairway and TSS)		4
Rules of the Road	3	
Navigation Failed to Ascertain Position	1	
Harbors (Safety Zone)		18
Rules of the Road	3	
Navigation Failed to Ascertain Position	1	
Misjudged Effects	7	
Not Classified	4	
Improper Mooring	1	
Carelessness	1	
Improperly Determined Height of Tide	1	
TOTAL		29

Table H-2 Delineation of Own Vessel Personnel Faults
Relevant to DWP Navigation

Personnel Fault Category	Impact Casualties Col	Ram	Grd	Non-Impact	Total
Rules of the Road Violations	44	3			47
Improper Lookout		2			2
Excessive Speed in Heavy Weather	4	1	1		6
Misjudged Effects	19	64*	129	4	212
Reliance on Floating NAVAIDS			8		8
Failure to Ascertain Position	2	7	75		84
Failed to Utilize Available Navigational Equipment	1	1	12		14
Vessel Sheered		2	2		4
Lack of Local Knowledge		2	4		6
Inexperience		1			1
Carelessness/Inattention	5	8	14	13	40
Improper Corrective Procedures	5	7	9	6	27
Poor Seamanship		2	4	1	7
Improperly Determined Height of Tide		3	27		30
Improper Safety Precautions	1		1	14	16
Other, Not Classified	4	16	13	6	39
DWP-Relevant Own Vessel Personnel Fault	85	119	299	44	547

* Of 137 total rammings involving misjudged effects, 73 were included due to involvement of tugs or of inherent problems of working close to rigid docks, bridges, pier, etc.

Note: Data obtained from the Vessel Casualty Reporting System for tankers 5,000 GT and larger for the period FY 1970-77.

The fault trees developed for this study to provide the causal linkages in DWP operations does treat personnel fault in considerable detail (see appendix D). From these fault trees it can be seen that such factors as "skills not properly applied," "inattention," etc., can lead to critical situations. These situations range from selecting a course that takes the vessel too close to shoals and obstructions to improperly execute avoidance actions.

As indicated in the fault tree discussion and as is apparent from the fault trees, per se, personnel faults in the "long time frame contributing factors" category can be and apparently usually are corrected before they lead to critical situations. This would be the case in the open Gulf where there are few obstructions and where traffic is more dispersed, which explains why personnel fault did not appear as a causal factor in the open sea in the data of table VI-2.

In the other zones, personnel fault was ranked as a hazard because (1) traffic is more dense due to "funneling" effects in straits, channels, and traffic lanes, and also due to fishing and pleasure vessels; (2) there are many obstructions such as drill rigs, reefs, etc.; (3) personnel faults in these zones can lead to high-risk situations, as is evident from the fault trees; and (4) the proximity of obstructions and increased traffic shortens time frames to such an extent that it is likely there would not be sufficient time to detect or correct situations induced by personnel fault.

It can be seen from the fault trees that personnel fault is a function of some basic, underlying factors (carelessness, incompetence, etc.) which lead to potentially critical situations (failure to post a lookout, less than adequate navigation, etc.). A representative sample of these underlying factors has been extracted from the fault trees for the insights it might provide in evaluating mitigating measures. Due to the large number of these factors, it was found necessary to group them in some consistent fashion. The grouping that was selected consists of four categories, defined as follows:

(1) Psychological/physical factors. Includes factors arising from some mental/physical condition including "personality problems" that impair performance. (Note that psychological and physical are lumped together because conditions that appear to be psychological are often due to some physical cause.)

(2) Abilities/capabilities factors. Includes factors that compromise the acquisition or application of skills and capabilities.

(3) Communications factors. Includes factors that preclude the requisite, on-board exchange of coherent information.

(4) Workload factors. Includes factors arising from work assignments or requirements that reduce the attention or time available for conning/navigation.

Table H-3 lists the underlying personnel fault factors assigned to each of these four categories. It can be noted from the table that the categories are not mutually exclusive. For instance, "haste" was assigned to psychological/physical factors on the basis that it is often a personality trait, but it might certainly be applicable to workload factors as well. Due to the nature of the factors, it is likely that such "overlap" would occur with any categorization scheme chosen. The four categories depicted were selected because they lend themselves to the evaluation of mitigating measures to a greater extent than other categories considered. However, quantitative evaluation of mitigating measures for these factors would require further research into the relative extent to which they are involved in vessel casualties and the resulting oil spills.

Table H-3 Underlying Factors Contributing to Personnel Fault

Psychological/ Physical Factors	Abilities Capabilities Factors	Communications Factors	Workload Factors
- Skills Not Properly Applied	- Lack of Skills	- Failure to Signal Intentions to Other Vessel	- Crew Size Not Adequate
- Perserverance in an Originally Bad Decision	- Incompetence	- Available Information Disregarded	- Crew Member Temporarily Leaves His Post
- Indecisiveness	- Lack of Experience	- Inadequate Information Conveyed at Change of Watch	- Crew Member Engaged in Routine Duties at the Expense of Critical Duties
- Fatigue	- Newly Assigned Crew Member Not Adequately Familiar With Vessel	- Wrong Information Conveyed at Change of Watch	- Master Distracted By Crew/Mechanical Problems
- Discomfort Due to Environment	- Judgment Error	- Inadequate Communication Between Watch Standers	- Master Distracted by Ship's Business
- Carelessness, Haste Inattention, Negligence	- Calculated Risk	- Pertinent Information Available on Board But Not Adequately Relayed to Bridge	- Bridge Officers Too Busy With Other Duties to Assess Impending Situation
- Panic		- Information Disregarded	
- Procrastination			
- Personal Animosity or Insubordination			
- Illness or Health Problem			
- Under Influence of Drugs and Alcohol			

452 all